Aalto-yliopisto
Insinööritieteiden korkeakoulu

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Impacts of traffic environment, weather, road conditions and maintenance on walking and cycling travel

Thesis submitted for examination for the degree of Master of Science in Technology.

Espoo 25.5.2018
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Diplomityön tiivistelmä

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Työn nimi Liikenneympäristön, sään, kelin ja kunnossapidon vaikutukset jalankulku- ja pyöräilyolosuhteisiin	
Koulutusohjelma Master's Programme in Spatial Planning and Transportation Engineering	
Pää-/sivuaine Spatial Planning and Transportation Engineering	**Koodi** ENG26
Työn valvoja Milos Mladenović	
Työn ohjaaja(t) Erica Roselius	
Päivämäärä 25.5.2018 **Sivumäärä** 93+9	**Kieli** englanti

Tiivistelmä

Kävely ja pyöräily ovat liikkumismuotoja, joilla on useita positiivisia ja moniulotteisia vaikutuksia. Niiden yleisesti tunnetuista hyödyistä huolimatta, ne ovat harvoin suosituin kulkumuoto, ja ihmiset käyttävät muita kulkuvälineitä, kuten autoa, niiden sijaan.

Tässä diplomityössä selvitetään, kuinka liikenneympäristö, sää, keli ja kunnossapito vaikuttavat jalankulkuun ja pyöräilyyn. Näitä tekijöitä arvioidaan kirjallisuuskatsauksen ja tapaustutkimuksen avulla, joka toteutetaan seututie 110:n jalankulku- ja pyöräilyväylillä välillä Turku-Kaarina. Kirjallisuuskatsauksessa käydään läpi edellä mainittuihin teemoihin liittyviä esteitä ja mahdollistajia. Esteisiin lukeutuu muun muassa vuodenaikaan liittyviä tekijöitä (kuten sää) ja keli. Mahdollistajia ovat esimerkiksi infrastruktuuri, verkostot, kampanjat, ohjelmat ja talvikunnossapito.

Tapaustutkimuksen tavoitteena on löytää keinoja jalankulku- ja pyöräilyolosuhteiden parantamiseksi (erityisesti talvella) kehittämällä liikenneympäristöä ja talvikunnossapitoa. Parannusten lähtökohtien selvittämiseksi, paikallisia olosuhteita seurattiin kelisensoreilla ja liikennelaskentalaitteilla. Kerättyä dataa täydennettiin empiirisellä tutkimustiedolla, joka saatiin kyselytutkimuksen avulla.

Tutkimuksen aikana (22.1.-4.3.2108) sää- ja keliolosuhteissa oli merkittävää vaihtelua. Tulosten perusteella vaikuttaa siltä, että lämpötilan lasku ja sadanta ovat merkittävimmät jalankulun ja pyöräilyn määriä laskevat tekijät, sillä liikennemäärien lasku oli suurinta kyseisten ilmiöiden aikana. Toisaalta, tien käyttäjämäärien lasku näiden aikana saattoi johtua myös lumisista ja jäisistä tieolosuhteista.

Talvikunnossapito on merkittävä jalankulun ja pyöräilyn mahdollistaja. Johtopäätöksinä on esitetty ehdotuksia jalankulku- ja pyöräilyolosuhteiden kehittämiseksi. Ne vaihtelevat yksityiskohtaisista liikenneympäristön suunnitteluratkaisuista talvikunnossapidon hallinnollisten rakenteiden yksinkertaistamisiin.

Avainsanat sää, keli, kunnossapito, talvi, pyöräily, kävely, liikenne

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Abstract of master's thesis

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Title of thesis Impacts of traffic environment, weather, road conditions and maintenance on walking and cycling travel

Degree programme Master's Programme in Spatial Planning and Transportation Engineering

Major/minor Spatial Planning and Transportation Engineering **Code** ENG26

Thesis supervisor Milos Mladenović

Thesis advisor(s) Erica Roselius

Date 25.5.2018 **Number of pages** 93+9 **Language** English

Abstract

Walking and cycling are active travel modes, which have several positive impacts on several different levels. Despite the generally known benefits of these modes, they rarely are the most popular ways of travelling, and many people still choose other modes of transport, such as cars.

This thesis looks into how traffic environment, weather, road conditions and maintenance impact walking and cycling activity. These qualities are evaluated through literature review and a case study on the pedestrian and cycling paths of road 110 between Turku and Kaarina. The literature review goes through barriers, which have a decreasing effect, and facilitators, which have an increasing effect, of walking and cycling related to themes listed above. Barriers include such elements as seasonal factors (i.e. weather and other uncontrollable variables) and road conditions. Facilitators include infrastructure, networks, campaigns, programs and winter maintenance.

The case study aims to find ways to improve walking and cycling conditions (especially in winter) through improvements in walking and cycling environment and winter maintenance. To determine the basis for improvements, local conditions were monitored with road weather sensors and traffic counters. To complement this information with empirical data by road users, a survey was performed.

During the study period between 22.1. and 4.3.2018 there was significant variance in weather and road conditions. It seems, that decreasing temperature and precipitation have the strongest negative impacts on walking and cycling volumes, since during these phenomena a drop in walking and cycling activity was noticed. However, the drop in traffic volumes during these events could have been a result of snowy and icy road conditions. Winter maintenance is an important facilitator for pedestrians and cyclists. As conclusions, recommendations and suggestions for improving walking and cycling conditions were made, ranging from smaller infrastructure design solutions of the traffic environment to administrational and bureaucratical simplifications among winter maintenance.

Keywords weather, road condition, maintenance, winter, walking, cycling, traffic, travel

Acknowledgements

This Master's thesis is a part of a larger project initiated by Traffic safety engineer Jaakko Klang from Centre for Economic Development, Transport and the Environment of Southwestern Finland. The project is realized in two years consisting of two parts, of which the first one consists of this thesis, studying and comparing methods to improve the conditions for walking and cycling, and also performing a study prior to any changes to these conditions. The impact of the methods applied are studied in the second part of the project in the winter of 2018-2019. Benefits of this project are planned to include testing of methods and equipment, assistive systems, friction measurements and organization of winter maintenance. Ramboll Finland Oy acts as the consultant of this project, which is funded by Centre for Economic Development, Transport and the Environment and Finnish Transport Agency.

I would like to thank my boss Emil Matintupa for offering me the topic, and Erica Roselius and Jaakko Klang for their advises, and my supervisor Milos Mladenovic for guidance on how to muddle through the process. I would also like to thank the rest of the steering group at Var-ELY and LiVi for their comments and material supplies, my colleagues at Ramboll for assisting with the study, Antti Hirvonen from Suomen Kuntotekniikka Oy for operating the weather sensors and other people contributing to this thesis.

In addition, I want to thank all the people from my student time for offering a balancing counter weight for studying, following in particular, IK'12, IK'13, MAIKH'14, MK'14, MAIKH'15, MKH'15, IE'15, ABP'16, ABP'17, KJ'18, VT and Tukkimiehet, not forgetting my friends, family, and close ones.

LTN

Espoo 24.5.2018

Pietari Peltonen

Table of Contents

List of Figures

List of Tables

1 Introduction

Walking and cycling are active travel modes, which have several benefits on several different levels. On individual level, they combine transportation and physical activity, providing a convenient and usually congestion-free trip, while also having a positive impact on health. On societal level, the more there are pedestrians and cyclists, the less there are cars in traffic, which means less congestion. Walking and cycling people are also healthier, which means savings for the society with decreased medical treatment costs. On environmental, even global level, increased modal share of walking and cycling will reduce emissions from traffic, and thereby increase air quality and help respond to climate change.

Despite the generally known benefits of walking and cycling, they rarely are the most popular ways of travelling, and many people still choose other modes of transport. Obvious reasons for these are for example too long distance, logistical issues such as heavy objects and lack of bicycle. However, people who travel by car often would have a chance to make the trip by bike or on foot. Even in situations where cycling would clearly be the best mode. Due to the beneficial potentials of cycling and low cycling levels, policy-makers in several locations are “showing increasing interest in encouraging cycling”. Despite the increased interest in cycling, the amount of attention given to it is a fraction compared to other modes of transport (Heinen et al. 2010).

Looking at financial aspects alone, walking and cycling are by far the best modes for personal transportation, when evaluating the big picture. They are extremely cost-effective travel modes, and in central position in developing sustainable transport systems. Some evaluations say, that every euro invested in cycling facilities brings as much as eight euros back. To compare, in Denmark every kilometer driven with a car costs the society 3.74 crowns, where every kilometer cycled only 0.60 crowns (The City of Turku, 2017). Winter maintenance is major facilitator of walking and cycling during winter. Investments and improvements in winter maintenance of walking and cycling facilities have also been shown to pay themselves back (Bergström, 2002). Furthermore, winter cycling has been noticed to strengthen the immune system, and also help against winter depression (European Platform on Mobility Management, 2014).

This thesis studies how traffic environment, weather, road conditions and maintenance impact walking and cycling activity. These qualities are evaluated through literature review and a case study on the pedestrian and cycling paths of road 110 between Turku and Kaarina using road weather sensors and traffic counters. This data is used to determine how the different factors impact walking and cycling conditions. These impacts are also explored with a user survey, which collects information about user experiences, preferences and traffic environment. Winter maintenance of the study area is monitored as well. Based on the results of these methods, suggestions are made for developing the conditions for pedestrians and cyclists through improvements in traffic environment and winter maintenance.

The study aims to find answers to following questions:

1. What kind of weather and road conditions are in the study location?
2. What factors affect cycling and pedestrian activity?
3. How can walking and cycling environment be improved for pedestrians and cyclists?
4. How winter maintenance should be improved and developed?

This thesis begins with a literature review about barriers, which have a decreasing effect, and facilitators, which have an increasing effect on walking and cycling. Barriers include such elements as seasonal factors (i.e. weather and other uncontrollable variables) and road conditions. Facilitators include infrastructure, networks, campaigns, programs and winter maintenance. Methodology introduces the case study context and data collection methods more carefully. Results present the outcome of the data collection. These results and findings are then analyzed in the chapter "Discussion," where also recommendations and suggestions for improving the walking and cycling conditions are presented based on previous studies and experiences, collected data, survey results and current winter maintenance.

2 Background

2.1 Barriers to walking and cycling

Even though the positive aspects of walking and cycling commonly known, many people choose not to use other modes of transport instead. The study by Heinen et al. (2010) showed, that people listed numerous negative reasons for this. “Too dangerous, too much traffic, bad weather, personal factors (too busy), lack of daylight, inconvenience, lacking sufficient fitness, uncomfortable, lack of time, being tired, too much effort, the bicycle being an uncharacteristic transportation mode and difficulties with trip-chaining” were the most frequently stated reasons not to cycle. It was also discovered, that certain factors are more important to some groups than others. Understandably, not all of these factors can be affected, but measures can be taken to improve cycling conditions and thereby increase the cycling rates.

Figure 1 shows the distribution of modal share per trip length and proportions of trip lengths. Figure 2 compares only walking and cycling against trip length. Distance seems to have a strong impact on walking trips: the longer the distance from origin to destination, the smaller the share of walking as a travel mode. A sharp decrease in the proportion of walking can already be noticed, when the distance is over one kilometer, and it is practically zero on trips longer than 10 kilometers. Cycling becomes more popular when the trip length is one to three kilometers, after which it also starts to decrease as a travel mode. In Figure 2, cycling becomes even more popular than walking on trips longer than 1 km. Based on these observations it can be said, that walking trips become, or could easily become, cycling trips when the trip distance exceeds one kilometer. (Especially) in Figure 1 can be seen, that the modal share of active travel modes in distances from one to seven kilometers could be significantly increased, as they still are reasonable distances for these modes.

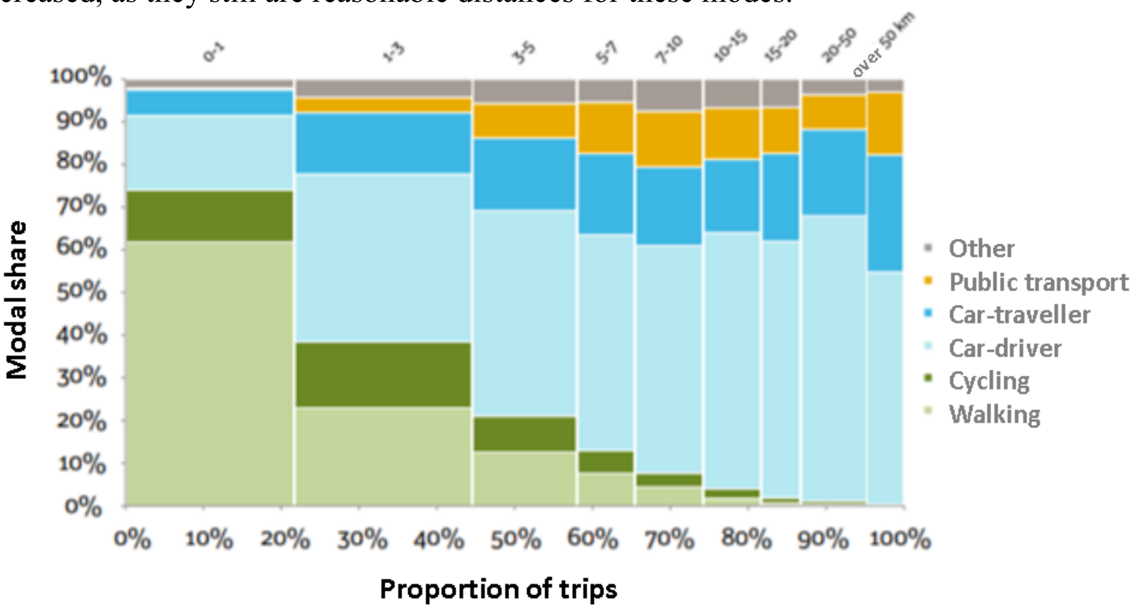


Figure 1 Modal share per trip length. Modified from Somerpalo et al. (2015)

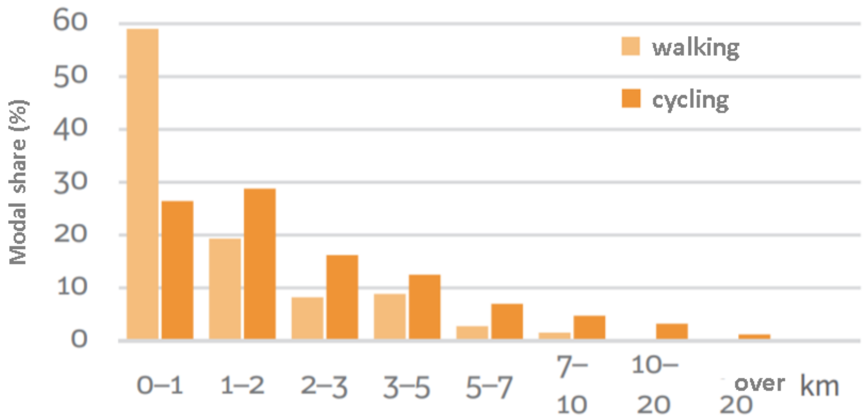


Figure 2 Modal share of walking and cycling per trip length. Modified from Finnish Transport Agency (2018a)

2.1.1 Traffic environment and conditions

In their study of 2016 ("Exploring User Perspectives to Increase Winter Bicycling Mode Share in Edmonton, Canada") Shirgaokar and Gillespie interviewed cyclists about different factors affecting the decision to cycle (during winter). Table 1 shows the conclusions of this study. Cyclist of this study could be divided in two categories: savvy and right of way cyclists. The category "savvy cyclists" consisted of somewhat average cyclists (67 percent of the interviewees). They were generalized as for example feeling unsafe and wary of traffic, using mostly cycling routes with minimal traffic, such as sidewalks, multiuse trails and other separated facilities. "Right-of-way cyclists" were characterized as more willing to cycle in motor vehicle traffic on streets with high traffic volumes, i.e. confident and enthusiastic cyclists (33 percent of respondents).

Table 1 Conclusions about how different factors impact on winter cycling, based on a survey by (Shirgaokar & Gillespie, 2016)

		Impact on Winter Cycling					
		Savvy Cyclists (67%)			Right-of-way Cyclists (33%)		
		Low	*Medium*	*High*	*Low*	*Medium*	*High*
Barriers	*High*		Unsafe conditions	Snow		Snow	Unsafe conditions
	Medium	Parked vehicles	Lack of public awareness				Lack of public awareness , Parked vehicles
	Low		Cold			Cold	
		Low	*Medium*	*High*	*Low*	*Medium*	*High*
Facilitators	*High*		Separated bike lanes	Snow clearing		Separated bike lanes	Snow clearing
	Medium	Network of bike lanes	Public education, Idaho stop			Network of bike lanes	Public education, Idaho stop
	Low	Sharrows	Destination amenities			Sharrows, Destination amenities	

The two main rows of the table include "barriers" and "facilitators". Barriers are factors that have a negative impact on the cyclists, whereas facilitators are factors that have a positive effect on cycling experience and cycling itself. The rows labeled with "high", "medium" and "low" describe the weight value of a barrier or facilitator, and the similarly labelled columns express the level of impact on the cyclist. "For example, "unsafe conditions" is a high barrier with medium impact for savvy cyclists who avoid vehicular traffic when possible, but it is a high barrier with high impact for right-of-way cyclists who ride with traffic most of the time." The priorities of barriers and facilitators was defined according to the frequency of the answers. For example: "sharrows are a low facilitator for both groups and have a low impact on savvy winter cyclists who do not bike on the street, but a medium impact on right-of-way cyclists who do bike on streets" (Shirgaokar & Gillespie, 2016).

One of the barriers labelled as high is unsafe conditions. They have a lower impact on savvy cyclists, probably because they use separated cycling facilities more than right-of-way cyclists. Parked vehicles are a medium barrier for both cyclist groups, but they have a higher impact on r-o-w cyclists, since they ride on streets. Lack of public awareness (car drivers not being aware of sharing the road with cyclists) is a medium barrier, having higher impact on r-o-w cyclists than savvy ones. Low temperatures had a similar low importance and medium impact level on both cyclist groups (Shirgaokar & Gillespie, 2016).

Amiri and Sadeghpour (2014) also studied the safety concerns of cyclists. 21 percent selected obstacles, such as parked cars, as a safety issue. Also fast moving cars were mentioned by about 21 percent of the respondents. Attitudes of car drivers was mentioned as the largest safety concern by three percent of respondents, and for example cyclist awareness programs for car drivers were emphasized. Other cyclists or pedestrians were not considered by many to be a safety concern. Cars driving too close to cyclists was also expressed as a concern, which is in line with previous study results confirming the advantages of separated bike lanes (see Amiri & Sadeghpour, 2014).

Safety can be divided into two types: objective and subjective. Objective safety is the more "concrete" type of safety, which can be measured unambiguously, for example by number of accidents per year for a specific location. Subjective safety is how an individual road user experiences the level of safety on the road. They may correspond to, but also differ from one another. When asked, people often mention safety as a reason not to cycle. Many studies (see Heinen et al. 2010) agree, that the higher the risk is, the less people assumingly cycle. The importance and perception of safety varies according to individual. Also, generalizations can be made according to for example gender and income (Heinen et al. 2010). However, according to Heinen et al. (2010), previous studies discovered cycling being experienced as the least safe mode of transport by all respondents, when comparing to public transport, driving a car, and walking. The connection between bicycle infrastructure and objective safety remained unclear, but subjective levels of safety were greater with bicycle-specific solutions.

The most severe type of walking or cycling accident is collision with a motor vehicle. Many studies state, that the possibility of collision with motor vehicles reduce the willingness to cycle (see Shirgaokar & Gillespie, 2016). However, the most common accidents are single accidents, such as falling or slipping (Swedish National Road Administration, 1999). Single bicycle accidents on the other hand, are rarely listed in the accident reports. They form approximately two thirds of all reported bicycle accidents in Sweden, Norway and Denmark (Bergström, 2002). The share of single bicycle accidents may be, and probably is even higher, since all accidents are not reported. It is estimated, that in Sweden approximately

20 000 cyclists get injured in traffic annually, from which about 4 800 require medical attention (Swedish National Road Administration, 1999).
In the United States, cyclist and pedestrian deaths and injuries are a severe public health problem, which has been widely disregarded. European countries have been labelled as putting emphasis on pedestrian and cycling centric land-use and transportation planning, and implementation of pedestrian and cyclist specific solutions has reduced the amount of injuries and deaths considerably. These methods include for example "traffic calming of residential neighborhoods; urban design oriented to people and not cars; restrictions on auto use; expanded education and training programs; and stricter enforcement of traffic laws" (Pucher & Dijkstra, 2000).

It is obvious, that different designs have different impacts on traffic safety. For example, Pucher and Dijkstra (2000) point out the impact of different orientation in the design of traffic environment. Figure 3 shows the relation of distance travelled by bike versus fatal accidents. Even though the Dutch and Danes have the highest distances travelled, they also have one of the lowest cyclist death rates. It is generally known, that in these countries cycling environment is highly prioritized, which indicates, that the amount of cycling accidents does not depend only on distance travelled, but also on traffic environment.

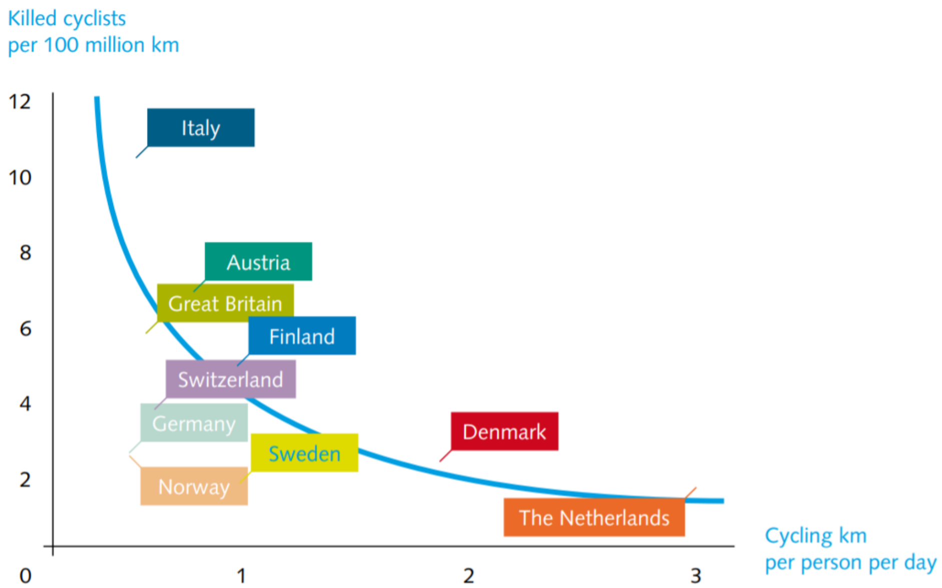


Figure 3 Relation between the amount of fatal cycling accidents and distance travelled (Huizinga, 2009)

Most notable barriers listed by pedestrians included traffic, with car drivers in particular, weather, inconvenience and lack of facilities. Other barriers included such things as lack of sociability, cultural factors, safety issues not related to traffic (crime), but also aesthetics. It was noticed, that more comfortable environment had an increasing effect on walking frequency. (Lorencet al. 2008)

2.1.2 Seasonal factors

Several studies in the United States report that cycling is clearly more common in the summer than in winter (and other seasons). The drop in the amount of cycling trips varies depending on the location: in parts of Northern America where the temperatures are low, the decrease in cycling activity is more notable than in areas with milder winters. In addition to the number of cycling trips decreasing, in Sweden it was discovered, that the maximum cycling distance decreases from 20 kilometers to 10 kilometers (Bergström & Magnusson, 2003) (Heinen et al. 2010). Liu et al. (2015) studied the impacts of weather on travel mode choice on a thirteen-year period, combining the results in Table 2. They concluded, that during winter the possibility of an individual choosing cycling as travel mode decreases. Additionally, it can be seen, that private car use stays relatively constant during each season. The variance is the largest among cycling: 9 percent units. According to Shirgaokar and Gillespie (2016), several studies say that the probability of winter cycling increases until certain age, after which it starts to decrease. In many studies it was found, that winter affects commuting trips less than other types of trips. Moreover, winter has lower impact on weekday and shorter trips than weekend and longer trips. Also, men are more likely to cycle in the winter than women.

Table 2 Trips per day and modal share by seasons (Liu et al. 2015)

Season	Average major trip made per individual per day					Number of days observed
	Walk	Cycling	Private car	Public transport	All modes	
Spring	0.451 (23.28%)	0.242 (10.66%)	1.125 (52.03%)	0.248 (12.92%)	2.098	980
Summer	0.326 (18.05%)	0.293 (14.76%)	1.119 (56.54%)	0.169 (9.04%)	1.943	1012
Autumn	0.408 (20.38%)	0.271 (12.16%)	1.158 (52.75%)	0.279 (13.75%)	2.142	1001
Winter	0.477 (25.56%)	0.120 (5.36%)	1.118 (54.00%)	0.263 (14.29%)	1.998	934

Value in parentheses is the mode share.

In cities where the cycling levels are high, most of the bicyclist cycle around the year, in wide range of temperatures and in every possible weather. During winter, however, the modal share of cycling decreases especially in cities, where the cycling levels are already low. In Copenhagen, Denmark, the modal share of cycling is about 30 percent. Four fifths of the cyclist continue cycling year around. In Netherlands, where the modal share of cycling is about 25 percent, even larger portion of cyclists continue cycling through the winter: 85 percent. In Graz, Austria, the share of trips by bicycle is only about 16 %, and almost half of cyclists use their bike only outside winter period. The trend is also visible in Vienna, Austria: with the modal share of only 5 percent, only 23 percent of cyclists continue riding their bikes in the winter. On the other hand, in Sweden and Finland, where the winter conditions are usually more demanding, the modal share of cycling is well over 20 percent, and 30 to 50 percent of cyclists continue riding in the winter (European Platform on Mobility Management, 2014). Somerpalo et al. (2015) studied the characteristics of cycling and factors affecting the cycling trips in their study of 2015, where they also compared the share of winter cycling per age group. The results can be seen in Figure 4 below. Dark blue bars present the share of cyclists on summer season (April-October) and light blue bars present the share of cyclists on winter season (November-March). The form of the figure is somewhat similar in both seasons. The greatest relative decrease in share of cycling happened among the elderly, with the age class six to eleven-year olds being second. The relative decrease was the lowest among 18- to 29-year-old young adults. These findings are somewhat similar to those by Shirgaokar and Gillespie (2016).

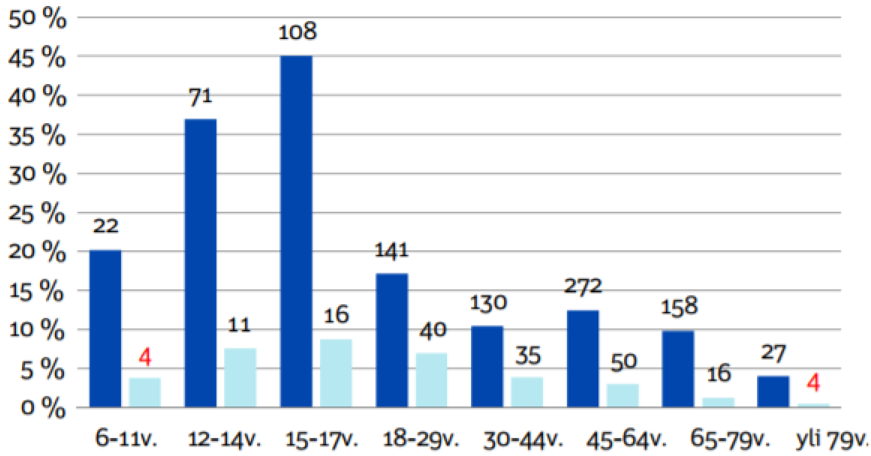


Figure 4 Popularity of winter cycling among different age groups (Somerpalo et al. 2015)

Many people think that winter cycling requires some specialized equipment, such as winter cycling track suit. This is often not the case, since for average riders a normal winter clothing is adequate. Usually one does not need studded tires either, riding a bit more carefully will do. In fact, in a study performed in 1998 in Norway, only every tenth winter cyclists said they use studded tires (Bergström & Magnusson, 2003). On the other hand, Sik and Granlund (2012) mention winter tires as a possible, important safety increasing feature in winter cycling. However, some attention should be paid to maintenance of the bike: in winter it tends to get dirtier faster, and due to road salt it may rust more rapidly, but cleaning the bike often enough and oiling the chains will increase the lifetime of the bike significantly (European Platform on Mobility Management, 2014).

Major reasons for not cycling in winter include darkness, cold temperatures, slipperiness, snow, wetness, precipitation and strong winds. Many cyclists do not continue cycling in the winter because of fear of falling due to low friction on ice. However, a few studies state that winter cycling can be even safer due to cyclists being cautious and riding on lower speeds (European Platform on Mobility Management, 2014) (Shirgaokar & Gillespie, 2016).

Perhaps the most apparent changes in outdoor conditions in the winter is the lowering of the temperature. There are several studies about the impact of temperature on cycling levels available. Parkin et al. (2008) say, that increasing of temperature increases the number of cycling trips, commuting trips in particular. The impact of temperature on walking and cycling was also studied by Liu et al. (2015), who ended in similar results (Figure 5). Bergström and Magnusson (2003) suggest that the decrease in amount of cycling during winters is more significant in locations with colder winters (Linköping vs Luleå). However, for example Oulu and Joensuu are the most active cycling cities in Finland, despite their colder winter temperatures and longer snowy seasons. (Maijala, 2011)

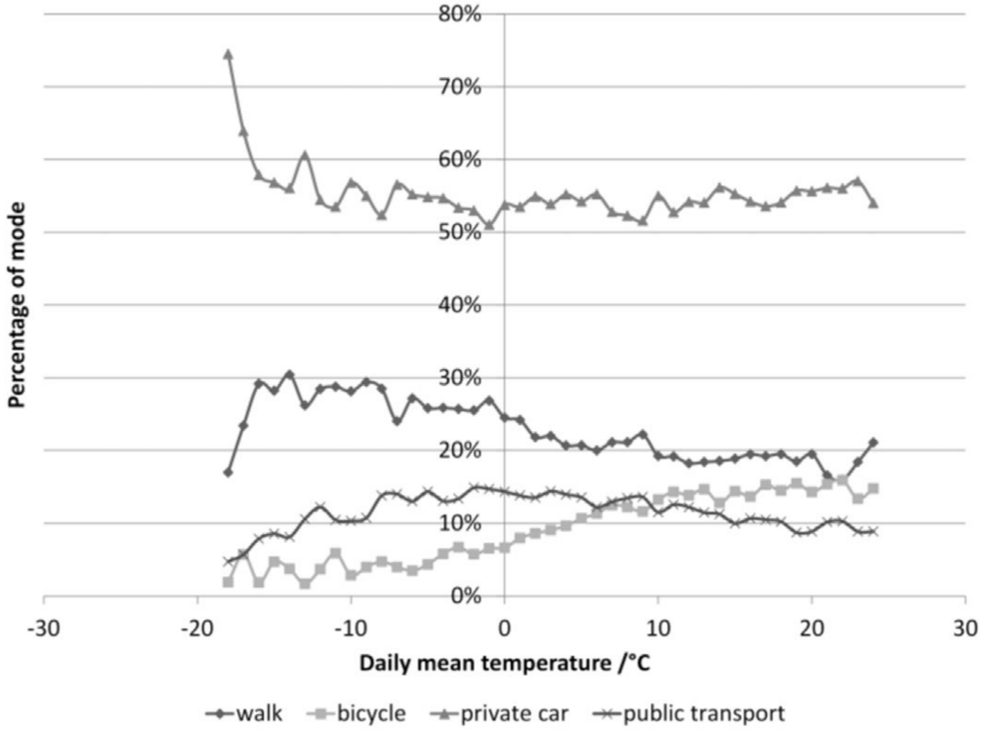


Figure 5 The relation between temperature and modal share (Liu et al. 2015)

The graph above (Figure 5) shows the modal shares of walking, cycling, private car use and public transport, according to study results by Liu et al. (2015) The modal share of car is fairly constant, around 55 percent. Only when it gets colder than -15 degrees Celsius, the share increases considerably. Walking and cycling seem to have an opposite reaction to change in temperature: when the temperature rises, the share of cycling increases and walking decreases, possibly indicating that a certain group chooses to either walk or cycle, depending on the temperature. Of course, temperature is not the only factor, but it can be linked to other factors related to colder outdoor conditions. The share of public transport increases roughly by ten percent when temperature increases from – 18 °C to zero °C, and then decreases by about five percent between 0 °C and 20 °C. This means that people switch to other modes when the temperature increases.

However, several studies state, that the lowering of the temperature alone does not have considerable influence on cycling. Normal winter temperatures are not a significant reason for the decrease in the number of cyclists (Shirgaokar & Gillespie, 2016). In fact, about 93 percent of active winter cyclists (and 84 percent of year-around cyclists) said that cycling was comfortable even below – 10 °C. Of all survey participants, 71 percent said they are comfortable riding in cold temperatures down to -20°C, even lower. (Amiri & Sadeghpour, 2014) Commuter bicyclists are affected by temperature less than other cyclists (Bergström & Magnusson, 2003) (Helbich et al. 2014). This could partly be explained by commuters having limited options. In another words, they might be depending on travelling by bicycle, and thereby cycle despite poor weather conditions (Heinen et al. 2010).

Precipitation seems to have a decreasing effect on the cycling levels (Bergström & Magnusson, 2003) (Liu et al. 2015). Study by Shirgaokar and Gillespie (2016) found out, that if it is raining in the morning, there is a drop in amount of bicyclists. This probably relates to the lack of options in case it starts raining after the morning trip. Having already cycled to work in the morning, people may be unwilling to leave their bike at the workplace, and cycle back home even if it is raining, especially when there are no other options available, such as public transport.

Figure 6 shows the results of study by Liu et al. (2015). As can be seen, there are no drastic changes in the modal shares related to precipitation. The popularity of public transport decreases slightly the more it rains. Share of private car increases as the precipitation increases, but in a moderate way. Walking seems to become less common the more it rains. The share of cycling changes in an unexpected manner, first decreasing from no rain to 0-1 mm, then increasing when the precipitation is 1-10 mm, decreasing again at 10-20mm, but reaching the highest percentage when the rainfall is over 20 mm. The authors believe that the "popularity of cycling" in heavy rain is due to heavy precipitation being common in the summer, when the amount of cycling is higher compared to winters. Also, the possibility of sampling error was present in the study (Liu et al. 2015). The alternating increasing and decreasing of modal share of cycling could possibly mean that the amount of precipitation has no major influence on decision to cycle: if it rains at all, some people choose another mode, whereas some do not care about the rain at all, and choose to cycle no matter what.

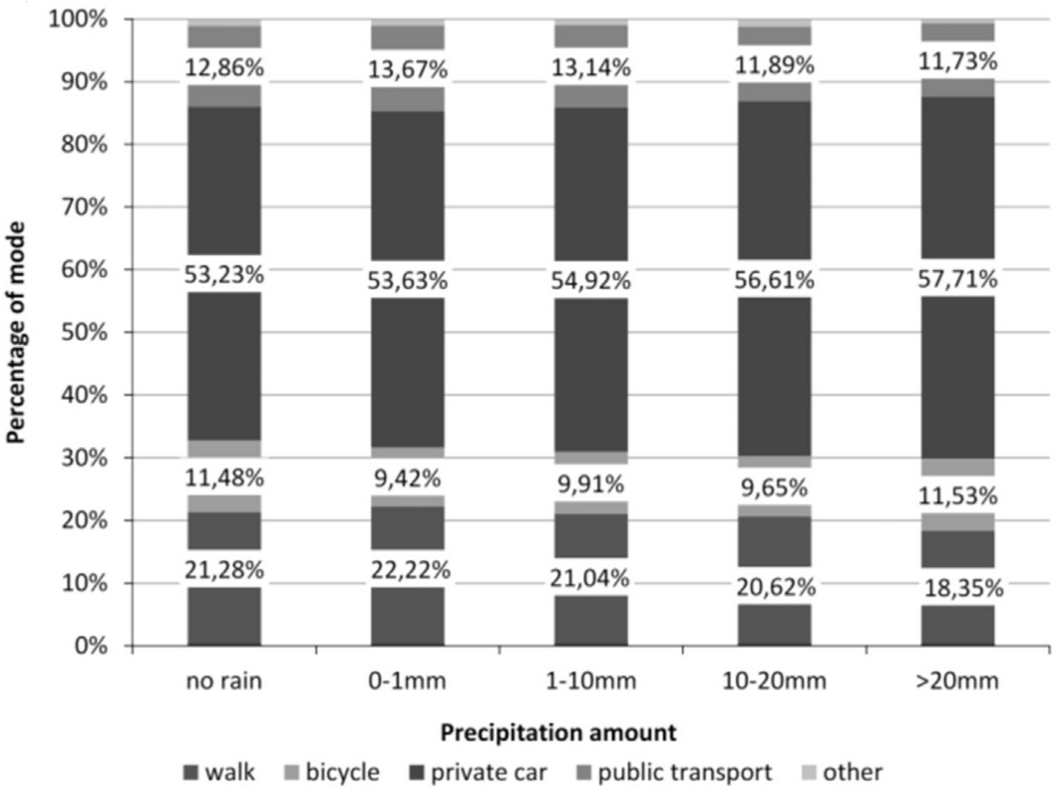


Figure 6 The modal shares of different transport modes according to various precipitation classes (Liu et al. 2015)

Location also seems to play a role in how much outdoor conditions affect cycling levels. Study by Helbich et al. (2014) revealed, that traffic in central urban areas was influenced less by the temperature, precipitation and winds. This was believed to be because of buildings providing shelter, but also because the microclimate in central areas tend to be slightly warmer.

It is worth noting, that cold temperatures and precipitation are indeed not the only factors to cause decreasing in the cycling levels during winters. Darkness has been found to have a negative impact commuting by bicycle. The lack of light seems to have a greater influence on women than men (Heinen et al. 2010). It is important to see and to be seen. During the winter the amount of light is lower than in summer, and street lights are not always enough. That is why it is important to use reflectors (which are often found on bikes by default). To see the street, road or path and other road users better, a functioning light is often needed and recommended (European Platform on Mobility Management, 2014).

Walking and cycling in winter have some special requirements considering the condition of the road, as the needs of pedestrians and bicycles considering the winter conditions vary from those of motor vehicles. For instance, bicycles are lighter in weight and the tire surface area is lesser than of motor vehicles'. This means, that snow and ice affect bikes differently than for example cars (Cebe, 2014). Poor road conditions are frequently stated as a major reason not to cycle. These conditions include for example cracks and unevenness, snow and ice, gravel and sand. The risk of accident for cyclists and pedestrians is evaluated five to ten times higher when there is snow and/or ice on the road, compared to bare surface. According to hospital data from Östergötland, slippery road conditions were the reason for 60 percent of all bicycle accidents. In Umeå, four out of ten accidents occur during winter (October to April). Slippery road conditions caused 40 percent of winter time cycling accidents. Also, loose grit has been reported to cause two to ten percent of accidents in Denmark (Bergström, 2002). According to Öberg et al. (1996) snow and ice are the most significant causes of single cycling accidents: 84 percent stated the accident was (at least partly) caused by ice or snow. Also Sik and Granlund (2012) say, that road conditions are a major factor in pedestrian and cycling accidents. Traffic safety of active travel modes could be improved significantly by developing winter maintenance (Ardekani et al. 1995). Results from improved winter maintenance in Umeå support this assumption (Bergström, 2002).

According to Heinen et al. (2010), there is a limited number of studies about the effects of surface quality. However, the literature available suggests that clear road conditions are more important to the elderly, right-of-way type of cyclists and women than other groups. In a survey by Wretling (1996), it was discovered that in winter time every fourth planned cycling trip was replaced by another mode. Walking replaced approximately every fourth cycling trip. Slippery road conditions were mentioned as a reason by 66 percent of answerers. Bergström (2002) says, that "winter cyclists seem to be insensitive to other factors than poor road conditions." For those who only cycle during summer, temperature and precipitation seem to play the larger role.

Several studies say, that a major barrier lowering the winter cycling rates is the presence of snow on bikeways (Bergström & Magnusson, 2003) (Spencer et al. 2013) (Miranda-Moreno et al. 2013). Shirgaokar and Gillespie (2016) noticed, that the lack of snow clearance on bikeways was identified as a reason not to cycle by both average and experienced cyclists. This would cause especially the experienced cyclists to choose riding on busier streets with higher traffic volumes due to better road conditions and level of winter maintenance. The authors suggest, that the regular plowing of bikeways increases the number of winter cycling trips significantly. Table 3 presents the importance of different road conditions per different cyclist groups, according to Bergstörm (2002). The results are somewhat similar to those by Shirgaokar and Gillespie (2016), assuming winter cyclists are characterized similar to right-of-way cyclists, and summer-only similar to savvy cyclists. Snow on road had a higher weight value for savvy than r-o-w cyclists. This is probably due to prioritized snow clearing, where the motor vehicle roads and streets are cleared first, thereby benefitting right-of way cyclists due to their route choice tendencies.

Table 3 The importance of different road condition factors for the mode choice according to the option of different categories of cyclists (Bergström, 2002)

Road condition	Winter cyclists		Summer-only cyclists		Never cyclists		Total average	
	Mean	Std. E.	Mean	Std. E.	Mean	Std. E.	Mean	Std. E.
Not cleared from snow	4.87	0.22	6.42	0.14	6.04	0.14	5.8	0.1
Slippery	4.54	0.23	6.31	0.15	5.87	0.16	5.57	0.11
Occurance of grit or debris	2.86	0.2	3.91	0.23	4.3	0.17	3.77	0.11
Cracks or uneven surface	2.88	0.21	3.79	0.24	4.11	0.18	3.67	0.12

Liu et. al. (2015) also studied the connection between the road condition and modal share. It was noticed, that when road conditions got worse, the share of bicycle trips decreased. Meanwhile the share of walking increased. The total share of cycling and walking combined was relatively constant, a bit over thirty percent, indicating, that when the road conditions get worse, part of cyclists switch to walking. The worsening of road conditions also had a moderate decreasing effect on private car use.

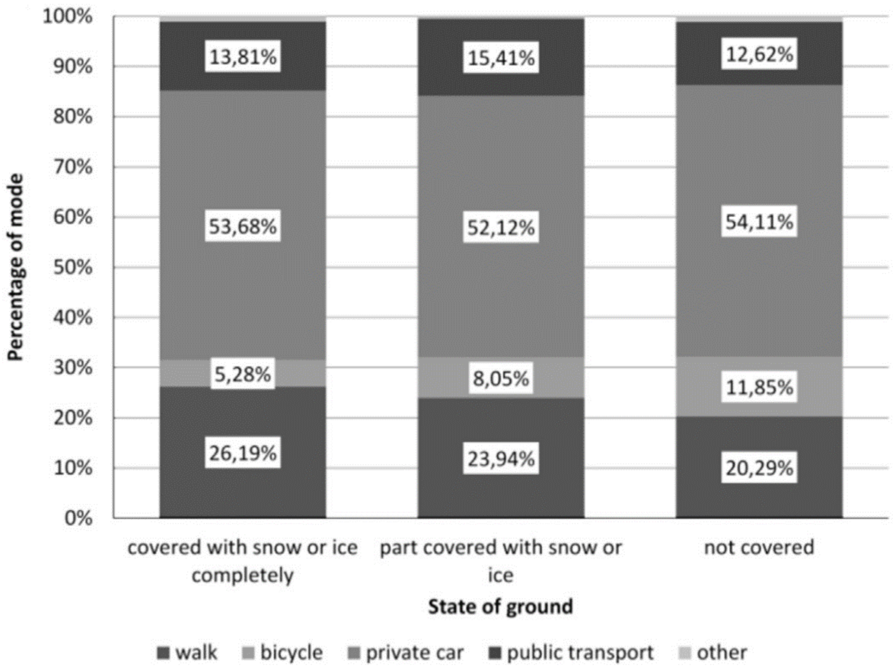


Figure 7 Modal shares according to road condition (Liu et al. 2015)

The safety concerns of winter cyclists were studied by Amiri and Sadeghpour (2014) as well. Approximately 61 percent of cyclists identified icy road conditions as a major safety concern. About 25 percent of respondents considered gravel and snow on bike lanes a safety concern. Here, the respondents often mentioned that the snow and its storage reduced the width of the bike lane.

Figure 8 presents two extremely slippery scenarios for pedestrians. The first one (on the left) is a situation, where the temperature is first above 0 degrees Celsius, and during the daytime drops below zero. Before the temperature going to subzero temperatures, the weather is wet: either raining, or the streets are wet from melted snow and/or ice. The liquid water then turns to slippery ice surface. Additionally, a layer of fallen snow on ice reduces the friction of the road even further. The second scenario (on the right) for extreme slipperiness occurs, when the temperature drops under zero degrees for a short period of time, usually during the morning-midday time-frame, turning the water on sidewalks into ice. As the temperature increases again, the ice starts to melt, and there is a layer of water on the ice, which brings the friction to low values. Additional rainfall on the ice makes the surface even more slippery.

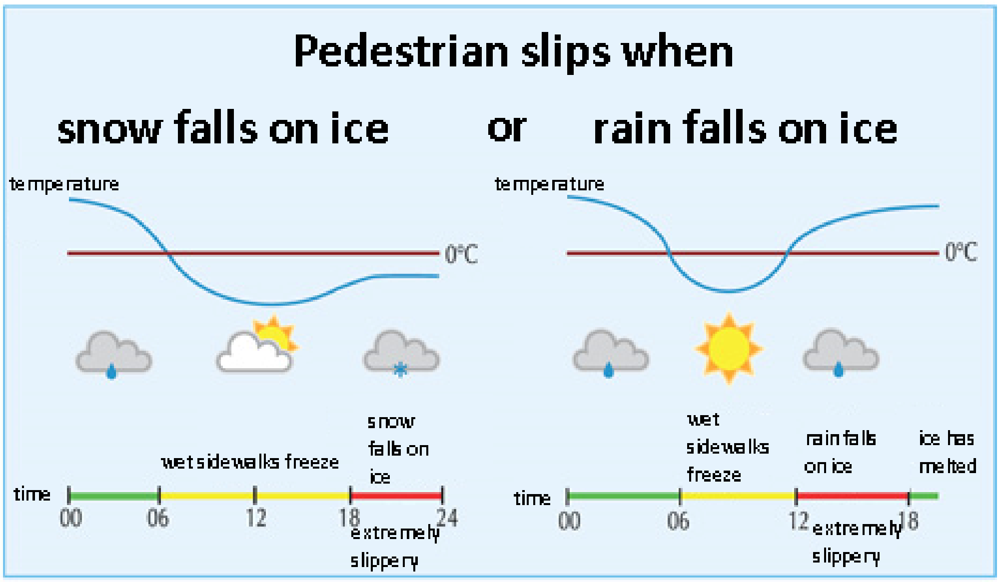


Figure 8 Slippery road conditions for pedestrians (Finnish meteorological institute, 2018)

2.2 Facilitators for walking and cycling

This section presents factors that are designed to enable walking and cycling, or further them and increase the safety of these modes as ways to travel. According to Maijala (2011), urban structure and infrastructure are the most important facilitators of walking and cycling. They are also a major factor in the feeling of safety experienced by the road users. Important are also immaterial facilitators, such as physical activity programs and campaigns.

2.2.1 Cycling infrastructure

Several studies show a positive correlation between improved bicycle infrastructure and amount of cycling. According to some studies, safety of the infrastructure was one of the major reasons discouraging the public to cycle. Thereby improving the infrastructure safety could attract more people to cycle (Amiri & Sadeghpour, 2014). This chapter presents the most common bicycle infrastructure components and their key characteristics.

One of the most fundamental questions concerning cycling is the space where to ride. The options vary greatly from bike-only paths to riding among the motor vehicles (Buehler & Dill, 2016). Typical accommodations for cyclists include:

- Bike lanes
- Cycle tracks
- Bike paths
- Sidewalks
- In mixed traffic with motor vehicles

Bike lanes (Figure 9) are dedicated spaces on roadways reserved for cyclists to ride on. In most cases, the lanes are separated only by pavement markings, which can be as simple as a common white line, or dashed line, but also different coloring of the bike lane is used and becoming more common. Bike lanes are ordinarily located between a lane for motor vehicles and parking spots or sidewalk. Several studies have noted a positive correlation between the availability of bike lanes and cycling volumes. Vernez-Moudon et. al. (2005) concluded, that living closer to a bike lane increased the likeability of cycling in general. A study by Dill & Carr (2003) concluded, that every mile of bike lane per square mile raised the share of bike commuters by one percent. On the other hand, several other studies stated that bike lanes and cycling did not have a strong relationship. For example, Dill & Voros (2007) found no correlation between available bike lane miles and ridership on nearby areas. Yet again, a study in Washington DC found a 250 percent rise in cyclist traffic during peak commuting hours after two years of setting up a buffered two-way bike lane, though it is uncertain whether if the increase came from new cyclists or from old routes (Buehler & Dill, 2016).

Figure 9 Two types of bike lanes. One next to parking, other without. (NACTO, 2014)

Bike lanes seem to have a little or no impact on the decision to bike. However, they provide a designated platform for biking next to cars. It also makes the cyclists feel safer compared to riding in traffic. On the other hand, when the other lane next to bike lane is reserved for parking, the cars have a need to cross the bike lane, which leads to dangerous situations for cyclists. Furthermore, opening of the doors of parked cars was considered a discomfort by the cyclists. The problem is considered more significant in rural areas, than in urban ones, since there the cyclists are used to it (Buehler & Dill, 2016) (Heinen, van Wee, & Maat, 2010). The space reserved for bike lane is taken away from the motorized traffic, and thereby combined with other measures a possible method to reduce the number of cars in traffic.

Cycle tracks (Figure 10) are bike lanes, which are physically separated from motor traffic. Sometimes they are titled separated or protected bike lanes. It is part of the motor vehicle highway, but physically separated by for example a concrete barrier, curb, or a buffer zone with pollards. Thereby the cycle track follows the alignment of the motor vehicle lane, but provides better protection from these vehicles than an ordinary bike lane (Buehler & Dill, 2016).

Figure 10 Uni-directional raised cycle track (NACTO, 2014)

The positive impacts of cycle tracks are larger than those of bike lanes. Studies performed in several cities showed that riding on cycle tracks was experienced positively, much due to increased level of safety. In addition, the number of cycling trips increased after the installation of cycle tracks (Buehler & Dill, 2016). The number of studies on cyclists diverting from previously used routes to newly constructed lanes, tracks and paths is relatively low, though. However, a study by Monsere et al. (2014) asked cyclists about alternative route choices in situation where there would not be a cycle track available. 17-83 percent (average of 65 percent) answered that it would not have an effect on their route choice. 24 percent would divert to another route. 10 percent would have used a different mode of transport (Buehler & Dill, 2016). Based on these numbers, roughly every fourth cyclist changes their route when a better riding platform is available. On the other hand, the majority of 65 percent wouldn't change their route, which raises more questions about the reasons behind these decisions.

Bike paths (Figure 11) are also physically separated from roadways, but on a larger scale than cycle tracks. According to Buehler and Dill (2016) bike paths seldom follow the road network, but instead "run through parks or along waterfronts." In Finland, however (excluding recreational bike paths) bike paths usually run along roadways. Another names for bike paths include off-street paths, trails, and greenways. Off-street paths may also mix bicycling traffic with pedestrians and other non-motorized modes (Pucher et al. 2010).


Figure 11 Bike path with one lane per direction. (Rhode Island Bicycle Coalition, 2011)

Several studies stated, that bike paths are an essential part of cycling networks. Many before-after studies indicate, that bike paths have an increasing effect on the numbe of biking trips and the modal share of biking as well. The share of bicycle trips was noticed increasing by 1-2 percent. It was also found out that bike paths would be popular among commuters, and they would commute even 20 minutes longer daily, if they could ride on bike paths instead of roadways. They also said, that they would cycle more often, given that the bike paths are easily reached and connect relevant destinations. People living close to bike paths had a higher probability to use them than those who lived further away. However, not all studies agree with bike paths, or other bicycle infrastructure, increasing the amount of bicycling significantly. These studies were performed in the United States however, so they might not apply worldwide (Heinen et al. 2010) (Buehler & Dill, 2016).

Despite increasing preference for separate bicycle infrastructure, further development is needed at least in the US and Canada. According to surveys performed between the years 1998 and 2012, in Northern America 50-90 percent of distance travelled by bike was on an unseparated roadway. Also, most cyclists had to ride at least for a part of the trip on roadways without separate cycling facilities. One reason for this is that the designated bike paths in Northern America are often limited and fragmented. The available paths also tend to locate along roads with higher motor vehicle volumes (Buehler & Dill, 2016).

In Canada, cycling on sidewalks is generally illegal, but however fairly common. Cycling on shared sidewalks is allowed, although not many cities rely on it as a method to increase cycling (Pucher & Buehler, 2006). Study by Aultman-Hall and Adams Jr. (1998) found that sidewalk cyclists experience more accidents and other events than those who cycle on bike lanes or with motor traffic. Srisurapanon et al. (2003) stated that 66 percent of cyclists preferred to ride on bikeways instead of sidewalks, and riding on sidewalks was described as rare.

Cycling in mixed traffic with motor vehicles is also an option. For this to be a comfortable solution for cyclists, special arrangements should be performed. Giving the priority to bike traffic over motorized vehicles is a common solution. An example of this is bicycle boulevards (or neighborhood greenways). These neighborhood streets are prioritized for bicycle traffic by discouraging car traffic. One way of encouraging cycling on these boulevards is by removing the stop-signs on intersections in the direction of the bicycle boulevard, which will allow a smoother and more continuous travel for the bicyclists (Buehler & Dill, 2016). Applications similar to neighborhood greenways are used around the world under various names, but commonly known as living streets. They allow motor vehicle traffic, but use design solutions to limit their use and speed.

Another ways to accommodate cyclists with motor traffic include for example cyclist-specific directional signs, cyclist markings (also known as sharrows) widened lanes and shoulders. Shared bus and bike lanes take the space away from cars, but they still mix (heavy) motor vehicles and cyclists. However, for example in the United Kingdom these shared lanes are popular among cyclists. On contraflow bike lanes bicycle traffic direction is opposite to car traffic. The safety impacts of these lanes have been studied in many countries, with varying results. Some say they increase safety significantly, some say they have not noticeable impact. However, according to Pucher, Dill and Handy (2010) no study has reported contraflow lanes to have safety decreasing impacts (Buehler & Dill, 2016).

Sharrows (shared lane -markings) are a low facilitator with a low impact on savvy cyclists, as they generally avoid motor vehicle lanes, but use them if necessary, and a medium on right-of-way-cyclists (Table 1), who prefer to ride among motor vehicles. When riding within traffic, sharrows provide safety for cyclists, as the space is marked to inform motor vehicle drivers that cyclists are present (Shirgaokar & Gillespie, 2016).

Figure 12 below shows the different bicycle accommodation alternatives collectively. They are arranged according to the amount of protection they provide for the cyclists, in another words, how safe they are for the cyclist. In this figure, bike path is titled as "Greenway".

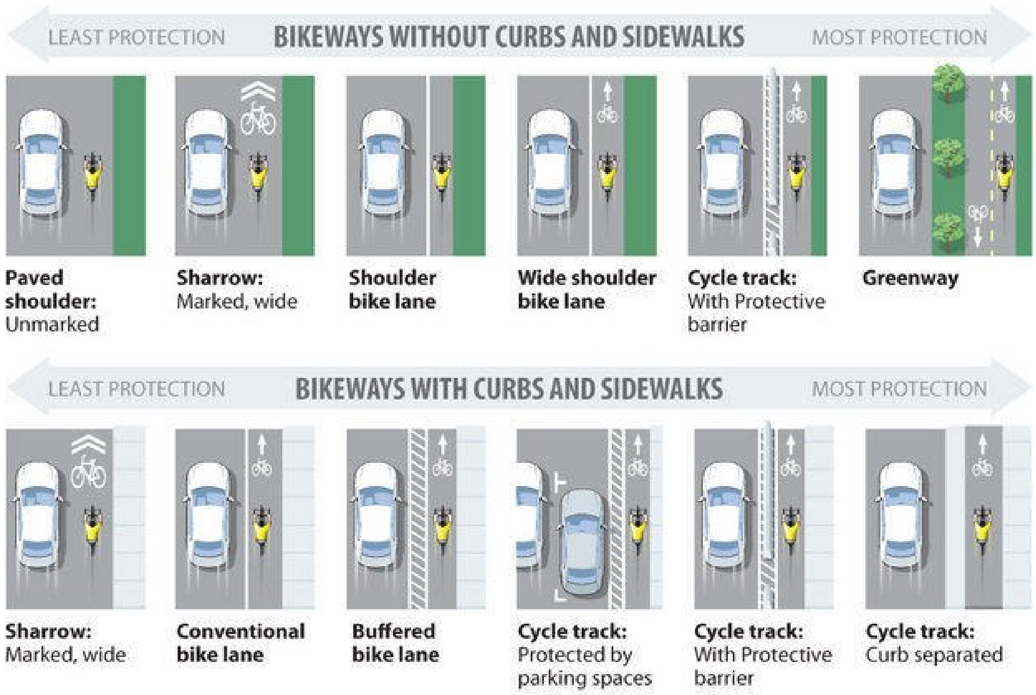


Figure 12 Different cycling arrangements and the amount of protection they provide respectively. (NOLA, 2014)

Several studies (see Heinen et al. 2010 p.5) confirm that the type of bicycle infrastructure plays a part in decision whether to cycle or not. Many cyclists prefer riding on designated bicycle paths to riding on bike lanes or shared roads without any cycling facilities. Pucher and Dijkstra (2000) suggested that the amount of cycling facilities per city or country correlates positively with the modal share of cycling and the level of bicycle safety. The evaluation of the bicycle facilities may vary significantly within the cyclists depending on for example socioeconomic situation, but the level of cycling experience plays a greater role: inexperienced cyclists find the bicycle facilities more important than the experienced cyclists (Heinen et al. 2010).

The amount of motor traffic next to cycling facility seems to have an influence on the preference of the cyclists about the facility itself. Roads including two lanes for motor vehicles were more popular among cyclists than those with four motor vehicle lanes. There is not a one simple explanation for this phenomenon, but on might be that on two-motor-vehicle-lane road the car drivers do not have as many other cars to pay attention to, and can therefore take the cyclists more into account. In general, cyclist seem to have a negative opinion about roads with higher volumes (Heinen et al. 2010). Also many studies agree that cyclists riding on roads favor calmer traffic conditions. Especially the inexperienced and young cyclists, women and risk-averse individuals experienced the most discomfort and fear of cycling among motor traffic. Streets without car parking and with fewer lanes, slower speeds, and lower traffic volumes were preferred. On the other hand, especially experienced cyclists preferred to ride on streets with other traffic instead of a separate bike path. Worth noting is also that the purpose of biking trip has an influence on the preference of the cycling space. Commuters do not mind riding among cars that much. Neither do the speeds or traffic volumes play a major role. Instead, when the purpose of the trip is not commuting, for example in Portland, cyclist used streets with motor traffic of over 20 000 vehicles daily only, if the calmer routes would have been twice as long. However, in Copenhagen, where the cycling facilities are commonly known as one of the best in the world, separate bikeways were preferred, but cycling on roadways wasn't found a negative experience (Buehler & Dill, 2016).

Destination amenities were considered as low facilitators, having a medium impact on both cyclist groups (savvy and r-o-w, see Table 1). These amenities include for example cycling-related facilities in the destination, such as bicycle parking and showering possibilities. Bike racks or other parking facilities provide user friendliness and security for bicycle storing (Shirgaokar & Gillespie, 2016). Several other studies agree, that safe bicycle parking is an important factor for cyclists, especially for commuters. The level of security of the parking facility is subjective: the more expensive the bike is, the more secure the cyclist wants the facility to be. It was also discovered, that men and younger people value the security more than other user groups. Most bicycle parking spots are found in sheltered or unsheltered bike racks, and have been found to have an increasing effect on cycling levels. Guarded parking is trending in Europe, in Germany, Netherland and Denmark in particular. Bike lockers are a secure form of temporary bicycle storage, most frequently found at train or metro stations. Cyclists seem to value bike lockers over bike enclosures and bike racks. Parking at train or metro stations supports the use of both cycling and public transport, and has been confirmed by several studies to increase the modal share of both cycling and public transport. Parking at bus stops is less common, but used in northern Europe. In North America, the linking of bike and bus trip is solved by installing bike racks on buses. Bikes can also be transported in rail vehicles, but they usually have some restrictions considering bikes onboard, such as prohibition during peak hours (Heinen et al. 2010) (Pucher et al. 2010).

The presence of other facilities next to parking is considered somewhat important. The availability of changing facilities, showers and lockers are appreciated. However, the absence of these facilities did not seem to have a significant effect on bicycle use. (Heinen et al. 2010) Providing facilities listed above could be a positive way for the companies to encourage their employees to cycle instead of using car.

The relationship between cycling rates and availability of infrastructure may be a bi-directional one. The better availability of bicycling infrastructure might not only attract more cyclists, but higher cyclist volumes could encourage construction for more infrastructure (Heinen et al. 2010). Several studies agree that improved cycling infrastructure has an increasing effect on cycling trips (Amiri & Sadeghpour, 2014). Study by Shirgaokar & Gillespie (2016) concludes, that "significant increase in winter cycling could be possible through supplying a network of separated bike lanes".

Shirgaokar and Gillespie (2016) suggest that the cycling infrastructure is often designed for summer use. Examples supporting this statement include such solutions as sharrows and painted bike lanes, which are covered with snow in the winter and thereby invisible. However, the same study concludes that winter cyclists can influence the improvement of the infrastructure and management within the limits the city provides. The authors recommend cities to design the cycling infrastructure to be operational during all seasons.

2.2.2 Cycling network

During the last twenty years, several levels of governance actors around the world have begun to promote cycling. Practically in every case this has been done by expanding the bike facilities. However, "the practice of providing cycling facilities is currently evolving from a focus on how to best install and design individual lanes or paths toward planning for entire networks of bicycle facilities." Networks include such elements as bicycle lanes, cycle tracks and cycling paths. In addition, for example special arrangements at intersections and calming of neighborhood streets have been executed to improve the safety and comfortability of biking (Buehler & Dill, 2016).

The role and importance of bikeway networks has lately increased vastly. In Finland several bikeway networks have been constructed and developed. Perhaps the most well-known segment is the Baana in Helsinki. Also in other countries the network planning has gained more attention. For example in the United States, the Department of Transportation has raised the priority of biking network "implementation and documentation" as a part of their "Strategic Agenda for Pedestrian and Bicycle Transportation" (Buehler & Dill, 2016). The United States Federal Highway Administration encourages designers and decision makers to treat walking, bicycling and other forms of transportation equally (Shirgaokar & Gillespie, 2016). In Northern America, Montreal, Canada, has been the leader in bikeway network development for several years (Cebe, 2014).

The continuity of the network and infrastructures is important. Cyclists prefer more continuous routes, and have a negative attitude towards facilities ending suddenly. Inexperienced cyclists appear to value the continuity of the infrastructure more than the experienced ones. As expected, the continuity is more important to transportation type of cycling than recreational, possibly due to recreational cyclists preferring to have freedom over their route choice. The continuity of cycling infrastructure on bridges also divides opinions. Especially inexperienced cyclists consider it important, but some studies (see Heinen et al. p 6.) state that the absence of cycling facilities on bridges makes no difference. As a conclusion Heinen et al. (2010) state that “while cyclists do have a preference for bicycle infrastructure on bridges, this does not cause them to make detours or change routes in order to use these facilities.”

Traffic lights, stops signs and other traffic controlling systems are an essential part of traffic management, but also cause delays, and therefore irritation in road users. Repetitive de- and accelerations cause cyclists an excessive amount of work, so it can be expected that cyclists try to avoid these sources of delay when choosing a route. However, more traffic lights tend to be on the chosen route than on the shortest one. This suggests that cyclists dislike traffic lights and other stopping causing traffic controlling, but they prefer avoiding other routes experienced more negatively (Heinen et al. 2010)

Central elements of the bicycle network are the nodes, in another words, intersections and junctions. In these locations the number of conflict points is significantly higher than on the lanes, tracks and paths alone, which requires intersection design and traffic controlling (Buehler & Dill, 2016). Several methods have been developed to improve the fluency and safety of intersections including bicycle traffic. As in the cases of different platforms, different solutions in intersections influence cycling experience, and thereby amount of cycling and modal share.

According to Buehler and Dill (2016), a very limited amount of studies on effects of treatments specific to cycling at intersection on volumes of cycling or preferences is available. A study performed in Vancouver discovered that cyclists have a preference to use signal crossings activated by bicycles (Winters et al. 2011). According to Monsere et al. (2014), 92 percent of cyclists felt safe riding through an intersection equipped with separate bicycle signal phases. Bike signals are more commonly used in Europe than in in the United States (Buehler & Dill, 2016).

Bike boxes, sometimes referred to as advanced stop lines, are designated waiting areas for bicyclists in intersection areas. They are located between the pedestrian crosswalk and the stop line for cars, as shown in Figure 13. Bike boxes are designed to give bicyclists better visibility to motor vehicles over conventional design solutions. This is especially the case when a motor vehicle is turning to a direction that requires crossing a bike lane (Buehler & Dill, 2016). Dill et al. (2012) found that 77 percent of cyclists felt safer crossing the intersection when a bike box was available. Similar to bicycle specific signals, bike boxes are not as common in the United States than they are in European countries (Buehler & Dill, 2016).

Figure 13 A bike box (NACTO, 2014)

Another method to increase a safety of a cyclists near a turning motor vehicle is to use a combined bike lane / turn lane (Figure 14) (NACTO, 2014). In such arrangement, a turning motor vehicle does not cross a bike lane while turning, but instead switches to a combined lane before the intersection area. Both bicycles and motor vehicles use the same lane for turning. Even though this type of intersection treatment increases the safety of cyclists, the motor vehicle still has to cross the bike lane before reaching the turn lane.

Figure 14 A combined bike lane / Turn Lane (NACTO, 2014)

Intersection crossing markings (Figure 15) guide the cyclist through the intersection via a specific path. Often it is an extension of bike lane over the junction area. The markings are usually sharrows, dashed lines and/or colored pavement (NACTO, 2014). The markings show the path of the cyclist to all road users, and thereby increasing the predictability of moving patterns of the cyclist. Intersection crossing marking may also enable a safer turning for cyclists by providing two-stage turning boxes. “Two-stage turn queue boxes provide bi-cyclists a way to make a turn on a multi-lane road without crossing from a bike lane to a motor vehicle turn lane” (Buehler & Dill, 2016).

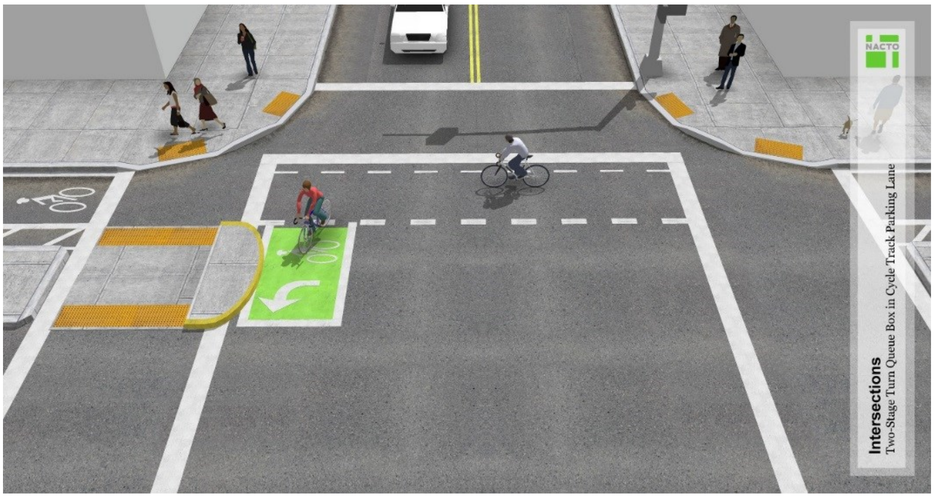


Figure 15 Intersection crossing markings (dashed lines) and two-stage turn queue box (green colored pavement) (NACTO, 2014)

Each intersection may contain a possibility of conflict. In addition, delays in trip-making are commonly experienced negatively among cyclists, which directly impacts on the decision to cycle (Heinen et al. 2010). Several studies (see Buehler & Dill, 2016 p. 8) agree that cyclists preferably avoid intersections that are unfavorable for them, in another words, intersections with traffic signals (excluding bicycle-specific traffic signals) and stop signs. However, the negative impacts of stop signs and traffic signals become less significant, when the amount of motor traffic in the intersection increases. This was believed to be due to time-savings or increased traffic safety for cyclist, but the importance of these factors could not be determined. An applicable solution to streamline the traffic in minor intersections is to apply laws that give cyclist the permission to ignore the stop signs. Although, the effects of ridership have not been studied (Buehler & Dill, 2016) (Broach et al. 2012). Swedish study by Gårder et al. (1998) discovered that installing a raised crossing had a decreasing effect on vehicle speeds, and thereby an increasing effect on safety and cycling volumes. The speed of cyclists increased slightly, however.

Some other measures increasing the safety of cyclists and the efficiency of the network include for example streets allowing car traffic but giving the cyclists a right-of-way, streets that allow car traffic only in one direction but bicycle traffic in both directions, lanes reserved for buses which cyclists are also allowed to use, networks redirecting motor traffic but enabling faster routes for cyclists. In general, solutions giving cyclists priority over motor vehicles. According to Pucher and Dijkstra (2000), the implementation of cycling network and cycling-safety increasing measures are particularly successful in Germany and The Netherlands.

2.2.3 Walking infrastructure and facilities

Basic pedestrian infrastructure is often simpler than bicycle facilities, since the travel speeds are much lower, and a single pedestrian takes less space than cyclist. However, special cases must be taken into account in pedestrian infrastructure design, to ensure safe moving of people with disabilities, such as blindness or moving with wheelchair.

The most basic facility to accommodate pedestrian is sidewalk, which are usually reserved only for pedestrian traffic. Sidewalk materials include for example concrete, brick and asphalt. Multi-use paths are facilities to accommodate both pedestrians and cyclists (Bushell et al. 2013). Sidewalks have been found to have an increasing effect on walking as a transport mode, and they are in important position in forming a well-connected pedestrian network: the more there are sidewalks available, the more direct routes there are usually available. Often attempts to improve walking conditions by implementing new sidewalks are accompanied by traffic calming measures (Saelens & Handy, 2008).

Walking trails are sometimes also known as pedestrian ways, nature trails or footpaths. They are usually thought as a suburban and rural walking infrastructure, often linked to recreational activity. “Establishment of walking trails can be a low-cost intervention that can facilitate walking by eliminating or reducing barriers and can encourage its maintenance because the trails become a permanent fixture in the community” (Wiggs et al. 2008) (Brownson et al. 2000). Boardwalks provide easier movement in otherwise challenging or uncomfortable surfaces, such as forests. They can also be installed to protect sensitive areas of nature, and may for example be equipped with educational signs (Kelaher et al. 1998). In Nova Scotia, the instalment of a boardwalk route increased the amount of walking among the residents of the area (Mangham & Viscount, 1997).

Attractiveness of the walking route also seems to have an impact on mode choice. In addition, proximity to attractive, public open spaces was noted to have a positive correlation in walking frequency by Saelens & Handy (2008). For example, trees and other plants may be planted to add attractiveness to the scenery, but also to increase the safety of the pedestrians (and cyclists) by limiting the access of motor vehicles and provide shelter (Massachusetts Department of Public Health, 2015). Different modes may also be separated physically by for example bollards, railings, pavement markings, gates and fences. Attractivity of walking infrastructure can also be improved with street furniture, such as bus stop shelters, and benches. Lighting improves the safety of all road users, since they become more visible, and are also able to detect possible obstacles and poor road conditions better. Lighting also brings security for pedestrians. Lighting is also important in most of underpasses. (Bushell, Poole, Zegeer, & Rodriguez, 2013).

According to Pucher and Dijkstra (2000), pedestrian zones are almost a standard (at least) in Dutch and German cities. These areas give pedestrians a right of way, even over bicycles. Often these zones are also car-free. Pedestrian malls are similar to pedestrian zones: they are designed to “promote safer walking in downtown areas.” Vehicles are prohibited either full time or separately defined. Often commercial activity is located on the sides of pedestrian zones and malls. Promenades (or esplanades), which are “paved pedestrian and bike trails,” are also somewhat similar to pedestrian zones, but without such commercial activities. Calmed residential streets (or living streets) combining pedestrians, cyclists and motor vehicles are used mostly in Europe. They restrict the speed of motor vehicles and driving through, which increases the safety of the unprotected traffic modes (Buehler & Dill, 2016) (Zegeer et al. 1994).

Similar to bicycle networks, also pedestrian networks include nodes and overlapping with motor vehicle infrastructure. For safer crossing of the roadways, several types of safety-increasing methods have been developed. Zebra crosswalks provide a designated area for crossing the street with motor vehicle traffic. They may be raised and equipped with signals for improved pedestrian safety, working simultaneously as a traffic calming speed bump for the motor vehicles. Often pedestrian traffic signals, some of which are automatically activated by pedestrians, are equipped with sound signals for the visually impaired. Crossings with button-activated signals are sometimes referred to as pelican crossings. Toucan crossings are crossings, which can be used by both pedestrians and cyclist to get safely to the other side of the road. Wider crossings should be equipped with middle islands, which provide a safe waiting area for crossing pedestrians (Pucher & Dijkstra, 2000) (Zegeer et al. 1994).

Overpasses (bridges) and underpasses (also known as subways) (collectively sometimes referred to as pedways) provide a crossing for pedestrians (and cyclists) without conflict points with motor vehicles. They are used especially in locations where crossing in the same level would be unsafe or practically impossible, such as highways, railways and rivers (Zegeer et al. 1994). They are also used to improve the smooth flow of traffic. The construction of over- or underpass is significantly more expensive than a conventional crossing, so the estimated number of users should be considered to evaluate the cost-effectiveness of the facility. Stairs, escalators and elevators are used for vertical movement, especially in locations, where the slope of the path would otherwise be too steep. These may also be found at over- and underpass entrances (Bushell et al. 2013).

Pavement markings are in important role with pedestrian facilities. Crossings may be marked with different colors, line types and widths. Especially in countries with left-sided traffic, pedestrian messages are painted on road surfaces to improve the safety of tourists in particular. Pavement surface textures are also used to help the visually impaired navigate and locate pedestrian crossing waiting areas. Curb ramps are implemented to ease the movement of those with physical limitations (Bushell et al. 2013). Pedestrian separators are used to direct pedestrians to particular crossing points (Zegeer et al. 1994).

2.2.4 Campaigns and programs promoting cycling

According to Pucher et al. (2010) "programmatic interventions aim to increase bicycling through promotional activities, media campaigns, educational events and other means." The general idea is to shift people from private motor vehicles to walking, cycling or public transport. A frequent problem in evaluation of the efficiency of the programs is that the impacts on cycling are rarely even measured, and thereby not reported. Instead the studies focus on trip reduction of vehicles. These include for example trip reduction programs, travel awareness programs and safe routes to schools -programs. Some studies suggest that the impacts on cycling are moderate: the effects are more notable within walking and public transport. However, cycling-specific programs seem to have more positive effects on cycling levels. Bicycle-specific programs are for example bike-to-work days, where employers encourage employees to cycle to work, "ciclovias", where streets are restricted for cyclists and pedestrians only for a certain time-period, different kinds of promotions, such as recreational cycling events etc., education and training programs aimed to increase cycling skills and awareness of cycling laws, bicycle sharing programs providing short term rentals of bicycles, giveaway and loaning occasions and repair programs. Legal interventions, such as helmet laws and speed limits for motor vehicles can also be considered as a form of program aimed to increase cycling and traffic safety.

Deffner et. al. (2012) say, that cycling transport and promotion connected to each other, and are in central role in forming a sustainable mobility culture. They have divided cycling promotion into different thematic categories, where the contents have connections to contents in other categories. These categories with different promoting strategies are presented in Figure 16 below.

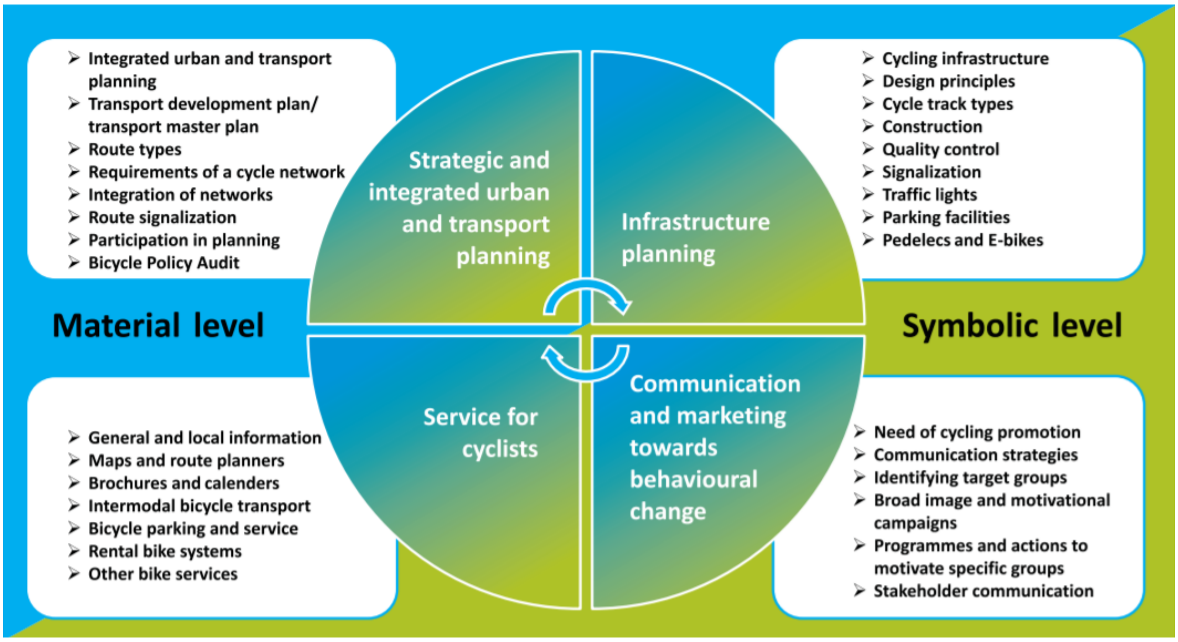


Figure 16 Cycling as a system in Mobile 2020 program (Deffner et al. 2012)

Dill and Voros (2007) say, that also the attitudes of individual people towards private cars are typically more positive compared to cycling. Especially in Northern America, the culture of car use is a major reason for low walking and cycling rates (Lorenc et al. 2008). On the other hand, in a study by Gatersleben and Uzzell (2007), people said that car-trips can be found stressful because of traffic, bad condition of road etc., whereas walking and cycling were found the least stressful and most exciting modes of travel. Additionally, people who have a positive image of cycling are more likely to commute by bike. Additionally, a person is more likely to do their work trips by bike if co-worker(s) or a person of same household is doing so as well. Furthermore, awareness of negative impacts of car use is a motive for some to prefer cycling (Dill & Voros, 2007).

According to European Platform on Mobility Management (2014) in some regions winter cycling is seen as unnormal, and winter cycling should be presented as a normal activity by normal people. In many cities and regions information is given about clothing, visibility and bike maintenance. In addition, many campaigns and programs have been carried out inform people about winter cycling and to increase the amount of winter cycling. For example, in Vienna, Austria, a free winter condition bike check service was held at important cycle route nodes. The transport department of Manchester offered guidance on finding a good cycling routes in the winter, also offering bike maintenance courses and private training sessions for commuters. In Brussels, winter cyclists got free bicycle lights and breakfast during the campaign. A significant amount of winter cycling education is also provided via videos (European Platform on Mobility Management, 2014). They are an effective way of campaigning for winter cycling as they are available for everyone on the internet, and also cost-effective.

The city of Örebro organizes a cycling school every summer. The purpose of the school is to teach adults to ride a bike. The campaign aims to decrease the number of trips made by car and increase the modal share of cycling. 150 people were encouraged to use bike instead of car to reduce carbon dioxide emissions and improve health. As an incentive, health tests were taken before and after the campaign, and compared to those who continued to use car (Eltis, 2014). The cities of Linköping and Gävleborg in Sweden handed out winter tires, cycle computers, bicycle lights, seat covers, helmets and reflective vests. As an extra, the cycle computers provided valuable data. In Finland, a recurring Pyöräilytalvi -campaign is organized by Pyöräliitto, which includes for example Instagram-competitions, handing out bicycle lights, co-operation with media and various events. It has been performed in many cities around the country (Rekola, 2018). Also annual winter edition of Bike Kilometre Competition has been held in Finland since 2012 (European Platform on Mobility Management, 2014).

Financial support is also granted for developing cycling and walking conditions in general. The European Union has established a project called Civitas Eccentric. It has started in 2016 in five European cities: Stockholm, Munich, Madrid, Ruse and Turku, and it will end in 2020. The project aims to develop smart and sustainable mobility in urban and suburban areas, and improving cycling and walking conditions is part of it (European Commission, 2018). The budget of the project is 17 974 993 €, of which the share of Turku and local co-operatives is 3 237 000 € (The City of Turku, 2017b). In Finland, funding for development of mobility management is granted by the state. In year 2018, a total of 1 160 000 euros was given to 31 different applicants. Several applicants applied funding for developing cycling systems and strategies in their area (Finnish Transport Agency, 2018b). In March 2018 the Finnish Ministry of Transport and Communications decided to promote the development of pedestrian and cycling conditions with 5 million euros (Ministry of Transport and Communications, 2018). The impacts of improvements of pedestrian and cycling paths on commuting on foot and by bike was studied in Kä-Py-program in Tampere (UKK-Institute, 2017). Promotion of walking and cycling has been performed and studied in Finland also earlier, for example with the Jaloin-Project between 2001 and 2004 (JALOIN programme cooperation group, 2004).

2.3 Winter maintenance

Winter maintenance is a major facilitator of walking and cycling during winter time. The objective of winter maintenance is to keep the transportation network suitable for traffic, often aiming to achieve road conditions similar to summer time. Not only does winter maintenance consist of physical road maintenance, but also of such things as planning, optimizing, resourcing, policies and financial issues.

Winter maintenance of cycling and walking facilities consists of several different components. For a cycling and walking surface to be suitable for use, it needs to be obstacle-free, and contain enough friction. The most important components of winter maintenance include removal and storage of snow, de-icing, prevention of icing and prioritization. “The regular maintenance of bike infrastructure is especially important in towns and cities with established bicycling networks and significant bicycling populations” (Cebe, 2014). According to Cebe (2014), many cities fail to fulfill the requirements for adequate quality of bicycling networks during the winter period. Winter maintenance is also a major factor in minimizing the costs of the maintenance of the road system, as it forms approximately half of all contract expenses (Kohonen, 2016).

In the simplest form, winter maintenance consists of two parts: snow removal and anti-skid treatment. Chemicals are used to prevent ice forming on the road surface. This method, however, relies strongly on (road) weather information and forecasts available. Chemicals are also used to loosen the bonds between the already fallen snow and formed ice on the road to ease clearing of the road surface. Snow, slush and ice is often removed by plowing, after which a new layer of chemicals is spread to melt the remaining snow, slush and ice. Also sand or grit can be spread to increase the friction of the road surface. The use of chemicals however, especially salt, has several negative impacts, so alternatives have been developed (Fwa, 2006). Often, there are also requirements considering the quality of the maintenance. Usually these deal with depth of snow on road, timing and duration of maintenance and surface evenness. There are often also requirements considering the friction level on the road, but these are seldom assessed (Bergström, 2002).

Winter maintenance for bike infrastructure and the amount of cycling can coarsely be summed up to following question: is winter maintenance needed when there are only few cyclists, or are there only a few cyclists because a lack of winter maintenance? (European Platform on Mobility Management, 2014) According to Bergström (2002), better winter maintenance could increase the number of bicycle trips as much as 18 percent, decreasing the number of trips made by car with 6 percent.

Bergrström and Magnusson (2003) say, that the drop in the number of cycle trips in winter time are probably due to "less favorable weather conditions." Cycling is influenced negatively by strong winds, low temperatures and snow or rain. In addition, road conditions are an important factor influencing the cycling experience and the decision whether to cycle. In Gothenburg, Sweden pedestrian traffic reduced by 25, and cycling traffic by 50 percent on icy/snowy roads compared to clear surface conditions (Öberg et al. 1996). In Norway, 53 percent of Winter cyclists refused to cycle on routes that were uncleared of snow. 27 percent said that a slippery surface was a reason not to cycle. Only a few of the answerers stated that darkness, low temperature or bad weather would cause them not to cycle. "This indicates a possibility to increase winter cycling, if the road conditions on cycleways were improved by a more efficient snow clearance and ice control." Comparison of survey results from Linköping and Luleå revealed, that the road users in Luleå were happier with the results of winter maintenance of cycling infrastructure than in Linköping. A possibility of Luleå residents being satisfied with the maintenance due to being accustomed to a harsher winter was considered, but later ruled out, meaning that the service level of winter maintenance in Luleå was better than in Linköping (Bergström & Magnusson, 2003).

Surveys by Bergrström and Magnusson (2003) revealed that certain parts of winter maintenance needed improvement. More frequent snow clearance and de-icing were mentioned most often. In addition, the removal of snow should occur earlier in the morning to enable comfortable commuting to work in the morning. Preventing ice from forming an uneven surface on the pavement was also among the most popular objectives. Additionally, "the importance of clearing continuous cycle routes, not leaving some parts uncleared" was brought up. However, the good condition of the road seemed more important for the non-winter cyclists, implicating that the most enthusiastic bicyclists ride no matter what the road conditions are (Bergström & Magnusson, 2003).

A research by The Dutch Centre of cycle-expertise Fietsberaad discovered that several communities did not have a clear winter maintenance policy. As a result, they made some general recommendations:

- Preparation of priority clearing plan, materials and gear should be started in the summer
- Installation of infrastructure complicating winter maintenance should be avoided. These include for example curves that are too narrow, bollards and too high curbs.
- Proper clearing technology should be used. In case of snow salting should be avoided and sweeping used. Use of smaller machines specialized for clearing cycle paths. (European Platform on Mobility Management, 2014)

Not all maintenance initiatives come from public sector: often inadequate maintenance is reported by regular road users. In Belgium, cyclists can report defective maintenance on web page, where an e-mail is sent to the authorities. This type of system was implemented for the first time in Zaanstad, Neatherlands for reporting slippery road conditions. Some cyclists have even taken the actions to their own hands, and applied a small plow to their bike and cleared the streets of snow themselves. This was especially notable in Calgary, Canada, where some enthusiastic cyclists plowed the cycle paths themselves until the city began to clear them (European Platform on Mobility Management, 2014).

One reason for inadequate winter maintenance is the lack of resources and money appointed to winter maintenance. For some reason, the financing of winter maintenance is not increased, despite it is known, that money invested in maintenance would pay itself back in several forms of savings. Öberg and Arvidsson (2012) studied the costs of wintertime injuries and winter maintenance and discovered that savings in pedestrian injury costs alone are greater than the costs of winter maintenance. Sik and Granlund (2012) say, that the costs of pedestrian and cyclist injuries are larger than those of car drivers and passengers. In addition to decreasing the number of accidents caused by poor road conditions, the amount of cycling during winter could be possibly be increased with more frequent maintenance (Ardekani et al. 1995). According to Bergström (2002), in Umeå, Sweden, improved winter maintenance of cycling paths decreased the number of cycling accidents, while the amount of cycling was increased.Some of the other relationships studied by Bergström (2002) are shown in Figure 17 below.

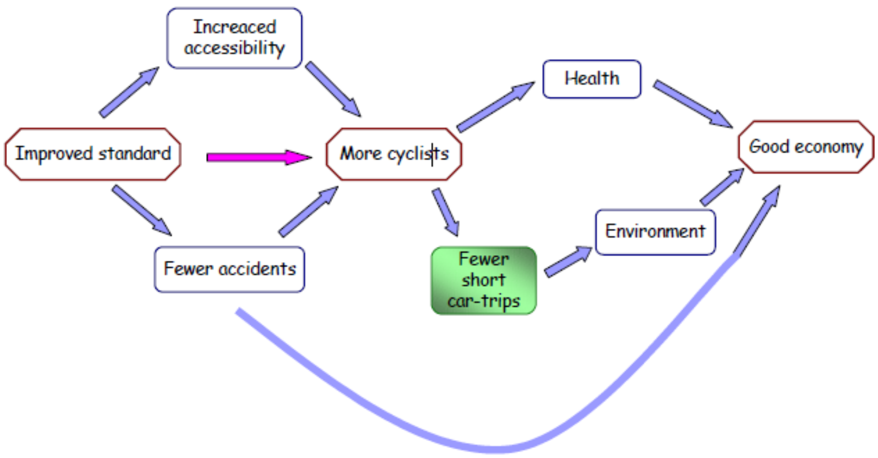


Figure 17 Connections between improved winter maintenance and societal aspects (Bergström, 2002)

2.3.1 Removal of snow

As stated before, snow and slush on the road is a major barrier especially for cyclists. Thereby removal of snow is an important factor in creating suitable and safe road conditions for pedestrians and cyclists. Consequently, several methods to remove snow have been developed. In addition, preparation for removal of snow has gained importance in planning of the facility.

One of the most important factors in snow removal is the design of the infrastructure. In Table 1 snow clearing has a high impact on both cyclist groups, indicating that plowing is a major facilitator of winter cycling among all cycling skill levels. In a coarse separation, snow removal may be divided into two types: shoving the snow to the side of the road or storing it elsewhere. Plowing, which is the most common practice of snow removal, pushes the snow to the ditch, shoulder, road edge or on a sidewalk buffer depending on the road type. In some cases, the snow removed from the road is transported to storage location. These are usually snow dump sites, commercial parking lots, or other such open places (Cebe, 2014) (Shirgaokar & Gillespie, 2016).

On roadways equipped with unprotected bike lanes, the snow is often plowed to the bike lane, making the bike lane practically inoperable. This leaves the cyclists with two options: either riding on the motor vehicle lane or riding close to the edge of the road next to the piled snow trying to avoid contact with it. Both options are undesirable not just only for the cyclist, but also for the motor vehicle drivers. The situation is unsafe and uncomfortable for the cyclists. To prevent these kind of situations, highway planning should be done with winter maintenance in consideration. Enough space should be provided for the side of the road to accommodate all the snow. In addition, the width of the bike lane should be designed so, that a reasonable amount of narrowing caused by storing of the snow is possible. Furthermore, if a buffer space between the lanes exist, it should also be scaled to fit the plowed snow (Cebe, 2014). In such occasion the plowed snow provides increased traffic safety, since there is a more continuous physical separation between the motor vehicle lane and the bike lane.

Parking on the street may become problematic during winter maintenance operations, especially if there is a bike lane between parking and motor vehicle lane. In such situation, restriction of parking during snow event may be a viable solution for snow storage location. Understandably, this is not a suitable solution for every roadway. It may, however, be well used on routes with bicycle priority. Providing cycling facilities parallel to major routes can also be helpful (Cebe, 2014) (Shirgaokar & Gillespie, 2016).

Several types of tools are used for snow removal. In simplified form, they consist of two key elements: a base vehicle, and an instrument for removing the excess snow. Both of these elements can vary considerably. “Truck mounted plow blades” consist of a large snow blade and a large truck. They are common in cities with demanding winter conditions. They often also carry deicing equipment, and are applicable on most roadways equipped with bike lanes. “Pickup truck mounted plow blade” is a pickup truck equipped with a snow blade. They are common in many cities that have a snow removal programs. Due to their smaller size, they are used on smaller roadways and other smaller places, where large trucks are difficult or impossible to operate. They can also be used to clear many protected cycle tracks and shared mode paths. This must be considered in the planning of the facility. Also pickup trucks may contain deicing gear (Cebe, 2014).

Sometimes larger maintenance vehicles may be too large or heavy for a pedestrian or cycling path, or the lighter structure of these paths might not carry such heavy loads, and these large vehicles may not fit into underpasses, tunnels or other narrow places. In future designs, these facilities should be designed wide enough to fit maintenance vehicles. However, numerous smaller snow removal vehicles are also used in winter maintenance. These utility vehicles include for example ATVs, tractors, bombardiers and “skid steers”. These snow removal vehicles follow the same format as larger vehicles: there is the actual base vehicle with mountable snow tool, and may contain deicing equipment similar to larger snow removal vehicles. It is also worth noting that using convertible maintenance vehicles, such as snow blade-mounted pickup trucks, easily becomes significantly more cost-effective than several different vehicles dedicated for individual tasks. The most common snow removing tools are plows, brushes and blowers. Snow brushes are effective in removal of light snow and slush, while snow plows and blowers are better for relocating heavier sets of snow. Compatibility of different tools and base vehicle enables a cost-effective use of tools and vehicles, as the same vehicle can then be used for summer time maintenance as well (Cebe, 2014) (Bergström, 2002).

As said, snow blades are not the only tools for snow clearance. Especially in locations with a small amount of snow, such as Denmark, brushes are an effective tool for removing snow and slush. Against ice, however, they are ineffective. That is why the snow brush vehicles are often equipped with deicing equipment. The combination of brushing and application of salt (brine) is known as salt brushing, “sopsaltning” in Swedish. With brine the amount of salt may be minimized, but in colder temperatures, different forms of salt must be used, and therefore the equipment should be compatible with both brine and (prewetted) rock salt (Salermo, 2015). Removing the snow with brush clears the road surface more carefully, but it is also more expensive than conventional maintenance, as brushing takes more time and salt needs to be spread more often (The City of Helsinki, 2016). Sometimes snow brushes are referred to as power brooms or street swipers (Bergström, 2002) (Cupina, 2015) (International Federation of Municipal Engineering, 2016).

The salt brushing system can be installed on a single vehicle, like in Figure 18. Another option is to put the salt brushing gear on a trailer, like in Figure 19. Other assemblies are also common, for example the brush being attached to the front of the utility vehicle, while the deicer tank and spreader are on a trailer. The use of trailer enables easy detachment of the salt brushing system, which also enables the use of salt brushing on a surface with more snow: the plow on the front of the tractor vehicle removes most of the snow, the brush finishes the snow removal and the deicer melts the rest of the ice. Such configuration was used in part of Helsinki test routes (The City of Helsinki, 2016). The snow brush module may also include a plow, suitable for removal of medium amount of snow (Salermo, 2015).

Figure 18 (left) Salt brush system on a single vehicle (Cykelpendla Hässelby, 2018)
Figure 19 (right) Salt brush system on a trailer (Umeå Kommun, 2018)

Heated bicycle paths provide a snow and ice-free surface, which will improve traffic safety and smoothen the traffic flow. The heating of pathways requires a lot of energy, and thereby isn't a sustainable solution in larger scale. However, the City of Amsterdam has experimented on heated bicycle paths that collects the heat energy from the road surface during summer, and stores it below the ground to be used during the winter. A mile of this type of road costs roughly 90 000 dollars, but does not require plowing or de-icing. Umeå uses heating on segments and pathways (altogether approximately 33 000 square meters) that are too difficult to be maintained conventionally (Cebe, 2014) (International Federation of Municipal Engineering, 2016).

Snow haulage is an important part of snow removal. Especially during very snowy winters, even the designed snow accommodation locations may run out of capacity, and the snow must be located elsewhere. This sets up challenges for snow dumping location positioning, as the transport distances should be kept short to minimize the costs and emissions. For example, in Helsinki and several municipalities in Sweden, snow is dumped in the sea. Other options may include dumping the snow into lakes and rivers. However, this method should take several environmental factors into consideration. The hospitals in Sundsvall are utilizing excess snow for cooling purposes, which has led to significant reductions in consumption of electricity and refrigerants (International Federation of Municipal Engineering, 2016).

Optimization of snow haulage is an important part of snow logistics. For the capacity to be utilized optimally, a sophisticated routing and tracking system should be developed. The system would map out the vehicles, and optimize their snow collection routes, directing them to the nearest snow dump site. This type of system could track performance, and also be used to enhance it. It would also be a useful tool for the maintenance management. Furthermore, it could be used to improve customer satisfaction, and reduce costs, as the data collected would help developing the process even further (International Federation of Municipal Engineering, 2016).

Recently, melting of snow has also taken place in winter maintenance. However, it is not a very common form of snow removal, at least yet. The City of Espoo was the first operator in Europe to take such snow melting equipment into use. One machine is capable of melting 80 tons (150-300 cubic meters) of snow each day, eliminating the need for transportation of snow, and thereby might bring some energy and emission savings (The City of Espoo, 2016). The efficiency and cost-effectiveness of this method compared to traditional snow haulage is yet to be studied.

In Finland, most of the snow removal is done by plowing. Brushing has been tested in a few cities on the most used cycling routes, but has not been taken into extensive, permanent use. The plowing of larger roadways is performed mostly with truck mounted plow blades, and graders, whereas the pedestrian and cycling paths are cleared with tractors, utility vehicles and pick-up mounted snow blades.

2.3.2 Deicing

Often snow on cycling or walking surface is not the only problem. Especially in countries, where the amount of snowfall is not the problem, slipperiness may still occur due to freeze-thaw cycles. Prevention of slipperiness of surface practices are divided into two primary strategies: reactive and proactive, sometimes titled as preventative and remedial. Both methods apply de- or anti-icing material on the road. The effect of the material is based on lowering the melting point of snow and ice.

Reactive deicing is performed after the snow event (as a reaction to weather event). The snow and/or ice is removed from the road surface, after which the deicing material is spread on the road "to break the bond between the ice and the road." As for proactive deicing practice, the deicing material is applied to the road before the snowfall. This procedure will melt the fallen snow and prevent ice forming on the road surface. After the snow event the road is cleared, during which a new layer of de-icing material may be applied (Cebe, 2014).

According to Cebe (2014), proactive application of de-icing is the most effective method of deicing. Proactive deicing also consumes less deicing material. North Dakota Department of Transportation has reported that proactive deicing required approximately only a third of the material compared to reactive deicing. Also, less plowing is needed when using proactive methods, as part of the snow on the road melts when it is in contact with the de-icing material. In Denmark, most of the winter maintenance is performed by salting, as the amount of snow is often low, but slipperiness does cause problems for cyclists (International Federation of Municipal Engineering, 2016).

A commonly used de-icing material is rock salt, since it is cheap and often readily available. Salt is often used on roadways, but less on cycling and pedestrian paths, as it is a highly corrosive material which causes staining of clothes and rusting of bikes and other vehicles containing metal parts. In addition, the salty melting water is harmful for the environment and concrete structures. Furthermore, the salt needs to be crushed to dissolve effectively. Temperatures are also a limiting factor in the use of road salt. A common road salt is effective only in temperatures above -10 ºC. Below these temperatures different chemicals may be used, such as magnesium chloride or calcium chloride. These, however, lose their effectiveness when the temperatures drop below -18 ºC (Cebe, 2014) (Bergström, 2002).

The salt may be applied to the road in another form as well. Pre-wetting the salt is an effective method to both decrease the consumption of salt, and in achieving better de-icing results. Dry salt tends to bounce off the road surface, where wetted salt does not bounce as much, which decreases the amount of salt needed in total. Water can be added to the point that all the salt is dissolved, and as a result salt brine is sprayed to road surface. The application of brine allows faster reaction times than normal dry rock salt (Cebe, 2014). Using brine also decreases the amount of salt needed, meaning smaller impact on the environment. Brine also does not need to be crushed for dissolving similar to dry salt, which is one reason cycleways are usually salted with brine, if they are salted at all (Bergström, 2002). On the other hand, salt brines have a narrower range of applicable temperatures.

Characteristics of chemical de-icers was compared in a master's thesis by Cupina (2015). Common road salt (NaCl) is by far the most common de-icing material. It lowers the freezing point of water, thereby melting it. It happens by breaking bonds between water molecules in ice and snow. Road salt and salt brine is effective down to -18 degrees Celsius, but the melting characteristics are weakened already at -6 ºC. The negative aspects of sodium chloride as a de-icer include corrosivity and environmental impacts, such as disrupting plants and contamination of groundwater. The use of NaCl as a deicer is justified with low price of the material: in 2015 it cost approximately 600 Swedish Crowns (~65 euros, with an exchange rate of 9,25 (European Central Bank, 2018)) per ton. Helsinki reported the price of grain salt to be 108 euros per ton, and 32-percent solution approximately 100 euros per ton (The City of Helsinki, 2016).

Calcium chloride ($CaCl_2$) is a salt similar to NaCl. The functioning of calcium chloride is based on exothermic reaction, meaning that the dissolution of salt releases heat, which melts the snow or ice and increases the temperature of the applied surface. $CaCl_2$ can be used in temperatures as low as -51 ºC, which is significantly lower than in the case of NaCl. Calcium Chloride also contains hygroscopic properties, which means it can retain humidity and water, creating a liquid layer on the road to suppress the dust. $CaCl_2$ is actually used for this purpose, however only during summer. Similar to NaCl, $CaCl_2$ is corrosive towards metals, and also concrete, which is one of the reasons it is not used widely in winter maintenance (Ihs & Möller, 2000). The environmental impacts are somewhat similar to NaCl (Blomqvist, Ferm, Gustafsson, & Jonsson, 2010). Calcium chloride cost 5000 Swedish Crowns (~540 euros (European Central Bank, 2018)) per ton, making it significantly more expensive than NaCl. Calcium Chlorde was tested in Sweden in a solution which consisted of NaCl, $CaCl_2$ and Molasses. In such solution (when used instead of only road salt) part of NaCl could be replaced with more environmentally friendly materials (Cupina, 2015).

Sodium formate (HCOONa) is also a salt with hygroscopic porperties. HCOONa does not have any known environmental impacts, and is biodegradable. Sodium formate is mainly used at airports, due to good de-icing properties without additive chemicals (Yong, 2000). HCOONa costs about 5500 Swedish Crowns (~595 euros (European Central Bank, 2018)) per ton (Cupina, 2015). Other formates may also be used for deicing purposes. The city of Helsinki tested potassium formate for a week. It had similar effects as salt, and is also biodegradable. However, it costs approximately five to ten times as much as salt (500-1200 euros per ton) (The City of Helsinki, 2016).

Lignosulfate is a non-toxic, hydrophobic by-product of paper industry. The environmental impacts of lignosulfate are minor, and the material decomposes in a way that causes minimal burden on the nature (Alzubaidi, 1999).The corrosivity of the material is lower than of water. It has mostly been used in solutions to decrease the amount of NaCl used, and alone it costs around 4000 Swedish Crowns (~430 euros (European Central Bank, 2018)) per ton (Cupina, 2015).

The ice melting capacities of six deicers in laboratory conditions was tested by Fay and Shi in their study from 2011. The results are shown in Figure 20. For detailed description of the experiment, please see the article. In the temperature of zero degrees Celsius, the differences in the performance of the deicers were relatively small. The ice melting capacity of solid sodium chloride based deicer (commercially known as IceSlicer) was the highest: 10.93 grams ice melted per 1 gram of deicer. Common (reagent) solid sodium chloride was not far behind: 10.70 grams of ice melted per 1 gram of deicer. At -5 ºC the capacities dropped significantly for almost every deicer. Solid deicers performed more effectively than the liquid ones. IceSlicer was reduced to 5.24 g of ice per g of deicer. The reduction in the capacity of "normal" NaCl was more moderate: at -5 ºC one gram of deicer melted 8.48 grams of ice.

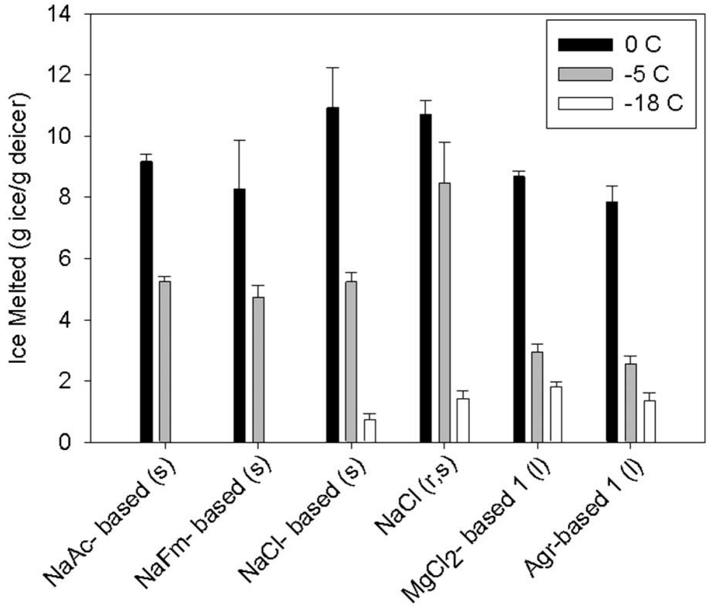


Figure 20 "Results from the SHRP ice melting capacity test, 60 min after application of deicers" (Fay & Shi, 2011)

At -18 ºC the performance of solid deicers decreased significantly compared to higher temperatures. Furthermore, the liquid deicers performed better than the solid ones in general. $MgCl_2$-based liquid deicer melted 1.80 g of ice per one g of deicer. However, solid NaCl still coped quite well against it: 1.43 g of ice melted per g of deicer. Solid NaAc- and NaFm-based deicers were ineffective at -18 degrees Celsius. (Fay & Shi, 2011)

Fay & Shi (2011) conclude, that the reagent-grade sodium chloride (NaCl) "outperformed all the other products by performing well at all three temperatures." They also point out, that despite the SHRP test provides comparable results of different deicer performances, reproducibility of this test has some issues, and the methods have been modified in similar studies.

Fay & Shi (2011) also tested the effect of deicers on friction levels on icy concrete surfaces. Figure 21 shows the results of the tribometer test. The friction coefficient of each deicer on ice is shown with white bars, and the friction coefficient of deiced concrete is shown with gray bars. From the figure can be seen, that there was not significant difference between liquid and solid deicers. However, some classifications can be made based on the results of tribometer tests: agro-based deicer resulted in the lowest friction values both on ice and deiced surface. The largest friction coefficient was achieved with solid NaAc/ NaFm-based deicers. The impact of sodium chloride based deicer on icy surface had the greatest variance, but it also almost reached the same level of friction on deiced surface as NaAc/NaFm deicers. The variance be by materials naturally found in the deicer, such as clay or other aggregate materials. The authors stated that the test results had great variance, possibly due to the immature methods used in the study. However, the test provides comparable guidelines for evaluating the effects of deicers on friction levels.

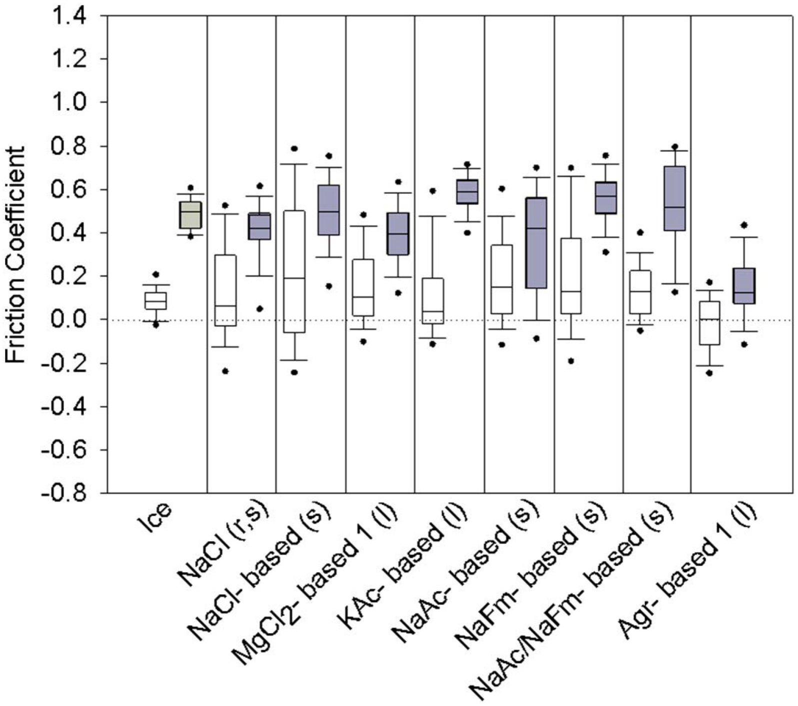


Figure 21 Friction coefficients of different de-icers on concrete samples (Fay & Shi, 2011)

The corrosive characteristics of the de-icing chemicals set some limits to their applications. KF- and chloride based deicers have been reported to be the most corrosive towards steel. The most steel-friendly deicers include Kac-, NaAc and NaF-based deicers. However, towards Galvanized steel Kac-based deicers are even more corrosive than chloride-based deicers. NaF-based deicers on the other hand are fairly non-corrosive to galvanized steel as well (Fay & Shi, 2011).

Fay & Shi (2011) also did an extensive comparison of noninhibited solid NaCl, inhibited liquid $MgCl_2$ and K or Na acetate/formate. Characteristics such as cost-effectiveness, safety, performance, corrosion to metals, impacts on pavement, impacts on the environment and wildlife were evaluated. Each characteristic was given a weight factor (average decision weight). Overall deicer composite indexes were following: NaCl 46.6, $MgCl_2$ 57.1, K/Na acetate/formate 46.5, meaning that magnesium chloride was evaluated the most applicable deicer (previously listed characteristics considered). The values show that there is still room for development in the field of deicers, since the perfect deicer would get an index score of 100. Furthermore, the weight factors are based on reported preferences of certain maintenance organizations, and thereby the results might not apply in every location. Additionally, the authors want to emphasize that the tests were performed in laboratory conditions, not taking into account UV absorption, wind and other such field conditions, indicating that new laboratory test methods should be developed to achieve results that imitate the real conditions more accurately.

The form of salt applied to road should be considered according to current and forecasted weather and road conditions. For example, the City of Fargo, North Dakota, has developed guidelines for the use of different forms of salt. The form of the salt applied depends on road temperature, road surface conditions and weather. In short, the amount of water in the solution is lowered the colder it is. City of Ottawa has determined the amount salt to spread according to pavement temperature, type of salt and road conditions (International Federation of Municipal Engineering, 2016). Different application types of salt were studied in Sweden in 1994 by Öberg (1995), according to whom the use of salt brine would decrease the amount of salt needed considerably: by half. The route could also be salted faster with brine than with dry salt. However, the working radius is lower, and cost of spreader is higher than of dry or prewetted salt spreading equipment.

Several alternative solutions have also been tested and used for de-icing. During the winter of 2014, New Jersey did a larger scale experiment of using pickle brine as a de-icing material, which lowered the freezing point to about -21 ºC. (Especially in Wisconsin, US) Cheese brine is a byproduct of cheese production, and can be used as such or as an additive. It has been said to be usable in temperatures as low as -29 ºC. It is also highly cost-effective, because it is completely a byproduct, and its normal disposal costs money. In Tennessee salt brine with potato juice as an additive is used. It was discovered in Hungary, when the by-product of distillation of vodka did not freeze in low temperatures. The amount of potato juice in brine is adjusted to the temperature (Cassidy, 2015) (Silverman, 2014). Iceland has used ursalt on the highways for a few years. Ursalt is used in fish industry, and when it no longer usable for food purposes, it is used on roads for de-icing (International Federation of Municipal Engineering, 2016).

Salt and other chlorides are not the only de-icing materials. Alternative deicers additive materials have been developed to reduce the negative effects of road salt. Sugars and sugar products can be used as deicers as well. For example, sugar beet juice or molasses may be added to salt or salt brine to improve its adherence to the road. It also lowers the freezing point of ice. Not only is it environmentally friendly and non-corrosive, beet juice is a by-product of agriculture that would otherwise be unused. Furthermore, the manufacturing of beet juice is inexpensive, and it can also be used with sand. Molasses are, like sugar beet juice, a by-product of sugar manufacturing process (Cebe, 2014) (International Federation of Municipal Engineering, 2016). It costs approximately 1800 Swedish Crowns (~195 euros (European Central Bank, 2018)) per ton, meaning it is relatively cheap compared to some de-icers, but still more expensive than road salt. Tests with molasses mixed with NaCl in the United States showed that better adherence on road lowered the required frequency of de-ice application, meaning savings in winter maintenance costs. Beet juice and molasses also have some negative aspects as well: they may attract animals due to their sugary content. In addition, they have an expiration date and the decomposing may produce odors (Cupina, 2015).

Salt is an effective method to prevent slipperiness in certain temperature ranges, but due to their corrosivity and harmfulness to environment, it is also problematic. Some pet owners have also expressed their concern about the impacts of salt and brines on paws of dogs. In Finland, salting is mainly used on roadway maintenance. Friction on pedestrian and cycling paths is enhanced almost exclusively with gritting. On special locations, however, salt is used. During the last few years, salting of cycling paths has also been experimented, but only on selected segments (The City of Helsinki, 2016) (Salermo, 2015). The rusting of gears may be prevented by lubing the gears and chains carefully, however. Brines and other by-products of agriculture and food processing industry have proven to be effective, environmentally friendly and remarkably cost effective, without major negative factors such as smell.

2.3.3 Gritting

Another conventional method for increasing the amount of friction is using sand or gravel (sometime knowns as grit). They are used to provide traction, as they do not have ice melting features. They also are non-corrosive, since their efficiency is based on mechanical skid prevention. However, salt or other de-icing material is often added to grit to prevent the grit in tanks from freezing to lumps. Sand, gravel and grit are an effective way to provide traction, but after the snow and ice have melted, it must be collected away. Otherwise it can lower the stability of cyclists. In addition, it can damage the mechanical parts of the bike (Cebe, 2014). According to cyclists, sand and gravel also tend to damage tires (The City of Helsinki, 2016).

The application of warm, wetted sand was introduced in Umeå, Sweden in 2006 and studied by VTI in the winter of 2011-2012. The experimentation provided promising results as it has not only improved traction, but also reduced surface ice. It is more effective than dry sand since it lightly sinks into the ice for better adherence, thereby not sliding away. Furthermore, the absence of salt makes this method non-corrosive and environment-friendly. The material is applied on the road with a special truck equipped with a water tank, heater, sand container and a spreader. Warming and wetting the sand is slightly more expensive than conventional sanding, but the method helps reducing the total amount of sand spreading needed. In total costs, warm, wetted sand was not significantly more expensive than normal sand (Cebe, 2014) (International Federation of Municipal Engineering, 2016) (Karhula, 2014).

A different form of mechanical friction enhancing was experimented in Oulu in the winter of 2016-2017. Burned and crushed clay was spread on a test segment of pedestrian and cycling path. The efficiency of the material relied on low density: the material floats, and therefore stays longer on the road surface of sinking inside the ice, decreasing the number of application times needed. Lighter weight also contains other advantages. Most of the interviewed road users did not notice a difference compared to traditionally gritted paths. This means, that the material could be used similarly to traditional grit, but with smaller material consumption and workload (Tervo, 2018). Another friction-increasing product relying on floating is Eco-IceGrip. It is a Swiss invention, where small wooden chips are treated with brine, and then dried before spreading. The light weight of the chips ensure that it stays on the surface. The deicer content in the wood is capable of melting snow and ice. Furthermore, it is an ecologic material due to production methods and renewability, and after winter it may be used for different purposes, such as energy production. The material is also pet-friendly (StopGlissPro, 2017).

Sand, gravel or grit are not corrosive, but may cause mechanical erosion of the road and damage the gears of the bikes. Grit probably needs to be spread several times during winter, as the material will sink, if the snow or ice melts. The grit below the freshly fallen snow also quickly becomes useless and might become plowed away, which means it will pile on roadsides. Excess amount of grit may be hazardous especially for bicyclists, since it may slide under the tire. In addition, in springtime, the collection of grit used in wintertime increases the amount of dust and other impurities in the air.

Regardless of the type of deicer or friction increasing material, it should be thought in advance, where and how much to store the material. There should not be a situation, where the maintenance performer runs out of materials. Thereby the storage should be big enough to accommodate the material for the needs of the entire winter. Other option is to make a deal with the material supplier about frequent enough deliveries. This however, is often more expensive than buying in bulk. Some municipalities in Germany on the other hand, have made successful partnerships with the material suppliers to overcome the challenges of limited storage facilities (International Federation of Municipal Engineering, 2016). The positioning of the storage is also a significant issue. It should be located so that it minimizes the distance travelled to refill. One option is to locate several smaller storages around the maintenance area.

2.3.4 Operations Optimization

Maintaining every bikeway after snow event is important but clearing them all at once immediately during or after snowing is practically impossible in most areas. To optimize the order of maintenance for bike infrastructure it should be determined and optimized, which paths to deal with first. This is called prioritization (Cebe, 2014).

There are many ways to evaluate the priority of a path. One variable to observe in priority class determination is the traffic amount on the path: the higher the bicyclist amount, the higher the priority should be, since it is used and thereby needed by more people than on some other route. Another way to determinate the priority is to evaluate the type of ridership on the route: routes to business districts and schools should have the highest priority (Cebe, 2014). Also, some special factors may affect the priority. For example, an especially steep hill may need to be cleared of ice first to prevent severe accidents.

Prioritization of bikeway maintenance may differ heavily depending on the location. However, they usually follow the same pattern: the most important routes are cleared first. The differences most often are about the quality requirements and standards. Often the quality requirements are defined by transport agencies or other such public administrative organizations. Cities, towns, municipalities or other local governances may have their own, stricter requirements considering winter maintenance.

In Reykjavik, Iceland following priorities are given for winter maintenance: 1 (main streets and most important connecting roads), 2 (bus routes and collector streets), 3 (through streets), 4 (local streets), B (parking), G (sidewalks and bus stations). The main streets (priority 1) are aimed to be always suitable for traffic. Actions are taken when the snow is approximately two centimeters deep, lower priority streets are cleared when the snow is about five to seven centimeters deep. Priority class G is divided into subcategories: Service 1a, 1b, 2, 3 and 4. 1a includes biking routes, which are cleared between 4:00 and 7:30. 1b includes prioritized walking paths, clearing between 4:00 and 8:00. Service class 2 consists of walking paths, which are cleared between 4:00 and 12:00. Service class 3 sidewalks of local streets are cleared when the facilities with higher priorities are cleared, however within 24 hours. Class 4 facilities are cleared after class 3 (International Federation of Municipal Engineering, 2016).

In Sweden, the maintenance vehicles are dispatched according to snow depth and type of snow (cold vs slush). Different municipalities may have different objectives for road clearance. For example, the dispatch criteria may be following: four centimeters of snow for streets, three centimeters for bike lanes, two centimeters for pedestrian paths. In the case of slush and sleet, the limit is 2 cm for all classes (International Federation of Municipal Engineering, 2016). In Linköping, the prioritized 90-km bicycle and pedestrian network is maintained by salt brushing. During exceptionally heavy snowfall plow is used. Salt is not used in temperatures below -10 ºC. The limit of snow depth for vehicle dispatch is only one centimeter, and the routes must be cleared within four hours from the fulfillment of the depth limit. Limits for network with lower priority are 3 cm and 8 hours. On this network plowing and sanding is used. In Umeå, Sweden, on prioritized cycling and pedestrian network, as much as four centimeters of snow is allowed before clearing must be performed (by plowing). Friction is controlled with warm, wetted sand and it is used proactively. On other cycling and pedestrian network, the limit for snow is six to eight centimeters and sanding is used when needed (Karhula, 2014).

In Denmark, the municipalities may prioritize the roads how they see fitting (International Federation of Municipal Engineering, 2016). In Copenhagen, three maintenance classes are in use: A, B and C. Class A covers all cycling paths, while class B consists of sidewalks. Snow limit for both classes is two to three centimeters. Class A routes are to be kept clear of snow and ice. Maintenance must be in progress within 45 minutes of alert, on class B routes within 75 minutes, and on class C 90 minutes. Roadways may belong to any of the three classes above. Cycling paths and sidewalks are cleared with snow brushes, but plows are used after especially heavy snowfall. The efficiency of winter maintenance in Copenhagen however, relies on proactive salting of cycling paths and sidewalks, keeping them continuously operational (Karhula, 2014).

The city of Tallinn, Estonia, has divided the streets into four priority classes, simply 1, 2, 3 and 4. However, they are numbered "reversely," so that Class 4 has the highest priority. Class 4 consists of "high-intensity public transport streets, sidewalks and roadways." They are to be kept completely clear of snow and ice: roadways within two hours of snow event, bike lanes and sidewalks within six hours. Salt is also used on sidewalks. Class 3 includes public transport streets and their sidewalks. Slush on roadways must be removed in five hours, deicing should be done in four, and the mixture of salt and snow should be removed from roads within eight hours. Class 2 facilities include side streets with medium traffic intensity. Up to eight centimeters of snow, slush or ice on the road is acceptable, but it should be cleared within twelve hours, and de-iced in eight hours. Deicing is to be performed on the entire route length. This time for sidewalks is twelve hours. Side streets with low traffic intensity belong to Class 1. They are allowed to have as much as ten centimeters of snow, slush or ice, and are to be cleared within 36 hours after snow event, sidewalks within twelve hours, and deicing within 24 hours. Only hazardous locations are deiced. Gritting is used on bicycle routes, sidewalks and public transport stops. The quality of the grit is carefully specified, and for example using sand is forbidden in most locations (International Federation of Municipal Engineering, 2016).

In Fargo, North Dakota, the priorities of winter maintenance are following: First the arterials and primary streets, second collector and secondary streets, third residential streets, fourth alleys, fifth city area snow haulage, and then haulage of arterials, collector- and residential streets according to snow situation (International Federation of Municipal Engineering, 2016).

The city of Järvenpää, Finland, uses three priority classes for their bikeways: A, B, and C. Class A routes, which are cleared first, are the main bike routes running from residential areas through town center. They are to be cleared within four hours after three centimeters of snow has fallen. Gritting is performed before seven o'clock in the morning. Next in priority order come Class B routes, which are the bikeways following the other major roads. They are maintained within four hours after five centimeters of snow on road has been reached. Gritting is applied as needed. In both classes A and B, plowing is performed before seven o'clock, if it has been snowing during the night. Class C routes run through parks and next to residential streets. They are maintained after Class B routes, before 10 in the morning in the case of night-time snowing. The sand and grit from the winter period is cleared from all routes before the first of May (Cebe, 2014).

The city of Oulu, Finland, has divided the cycling and walking paths into two classes: I and II. Primary methods used for winter maintenance are plowing and sanding, but with separate permission salt may be used in some locations. On Class I routes, the limit of snow depth is two centimeters and three during snowfall. Snow removal and sanding are to be performed before seven (in the morning) and four (in the afternoon) o'clock. After six in the evening, the snow must not be plowed unless the snow depth is over 8 centimeters. On Class II routes the limits for snow depth are three and five centimeters. Snow removal and sanding is performed after class I routes (Karhula, 2014).

According to Cebe (2014) the greenway network in The Twin Cities area (Minneapolis and St Paul in Minnesota) is one of the most comprehensive ones in the United States. Keeping the greenways clear is highly prioritized, because they have a high level of use year around. Commonly, the network is cleared in the next 24 hours of snowfall. The stock consists of pick-up trucks and skid steers.

The City of Calgary, Canada updated its route prioritization system in 2012. Priority I was given to all roadways that contained bike lanes, and after a snow event they will be cleared first. Plowing and de-icing is continued until the pavement is completely snow and ice-free. The remaining marked bike routes are labelled as Priority II. "They will be cleared 48 hours after the snow stops until bare pavement is achieved." In Calgary the lowest priority is given to residential streets, which means they will be plowed last (Cebe, 2014).

The Wisconsin Department of Transportation provides a guidance for prioritization of routes. Much like in the cases of previous cities, highest priority is given to routes with the heaviest traffic volumes and important connections. The winter maintenance program will be determined by each municipality, but following factors should be considered:

- "Expected use by bicyclists and pedestrians"
- "Parallel options for bicyclists and pedestrians if the path is not passable"
- "State statue 81.15 regarding the liability for accumulation of snow" (Cebe, 2014)

According to Cebe (2014) Montreal, Canada, has been the top city of cycling culture and bicycle network development in Northern America for several years, and its network includes over 350 kilometers of bikeways. In 2008 the city prioritized approximately 60 kilometers of bikeways as "White Network". The maintenance strategy has since moved more to direction of keeping as much of the network clear as possible. The prioritization of protected bikeways remains high in Montreal, since they have up to 800 bicyclists daily, and as much as 200 to 230 centimeters of snow annually.

In Örebro, Sweden, the priority is given to the cycling network, consisting of 15 high-quality cycle paths, over roads to ensure the high number of cyclists during winter as well. The city of Örebro guarantees to clear the cycle paths from snow within twelve hours of snow event. Spreading sand on cycle paths is emphasized in winter. The removal of sand is also prioritized in the spring before roads (Eltis, 2014).

In Finland, the prioritization of maintenance of the transport network depend on the ownership of the road or path. Roads and adjacent facilities are maintained according to requirements defined by the Finnish Transport Agency. These requirements for pedestrian and cycling paths are presented in chapter 3.1.2 "Winter maintenance requirements in study area." Maintenance of roads, streets and path owned by cities and municipalities may be prioritized the how the city or municipality officials see fitting.

With route maintenance prioritization, also optimization of maintenance facilities should be considered. Optimization may be performed in various levels. These levels are illustrated by Glavić et al. (2017) in Figure 22. With vehicle fleet and workforce optimization, not only can efficiency of maintenance be improved but also cost-effectiveness increased. Another considerable enabler of increased efficiency is utilization of spatial data to determine the positions of depots together with routing. Real-time optimization is performed based on the current weather, forecast and road condition data available.

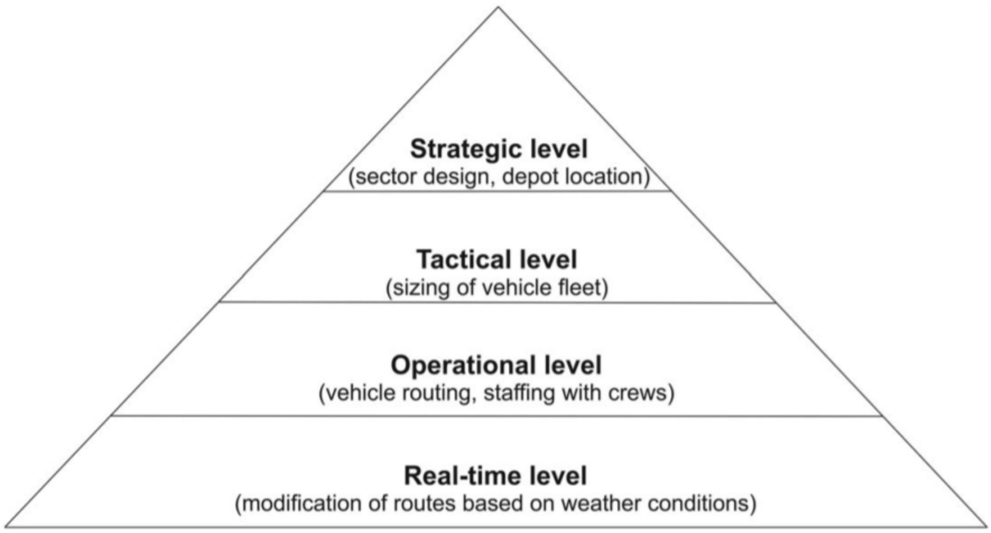


Figure 22 Levels of winter maintenance (Glavić et al. 2017)

2.3.5 Financial operation and policies

In Iceland, the winter maintenance is divided into two categories: roads and sidewalks. The public sector and contractor make a contract for maintenance of main roads and carriageways. These contracts are made for three years, and include an option for extending the contract. The fulfillment of the contract is enforced by inspectors, who make sure that the equipment is according to requirements before the beginning of winter. Maintenance contracts are made separately for sidewalks and bike routes, for one year at a time, with an option for extension. The equipment is inspected same way as the equipment for main streets (International Federation of Municipal Engineering, 2016).

Norway has divided the country into five different climate zones, according to which the maintenance methods are developed. All the national and county roads are classified according to importance and traffic volume. They are under responsibility of The Norwegian Public Roads Administration, and the maintenance actions are defined by qualities and standards. Usually, contractors perform the maintenance. Municipalities are responsible for the municipal roads. Many municipals utilize contractors, but also use their own work-force. There is significant variation between the standards and configurations in different municipalities. Contractors using snow-clearing equipment owned by the municipality is a common arrangement in some areas (International Federation of Municipal Engineering, 2016).

In Denmark, the State is responsible for maintenance of the State Roads. Maintenance of other public roads are under responsibility of the municipalities (International Federation of Municipal Engineering, 2016). In Copenhagen, the contracts for maintenance of cycling routes and sidewalks are made per route, for four years at a time. In intersection areas, the last contractor to arrive cleans the area. The City of Copenhagen manages the maintenance itself. Conditions are monitored, and the vehicles of contractors are dispatched by city officials in a dedicated control room, which is in use around the clock. Quality of the winter maintenance is monitored continuously by the employees of the city. Monitoring is performed with GPS locators and quality controls. In addition to continuous dialogue with the contractors, the maintenance requirements are discussed with the contractors before each winter (Karhula, 2014).

In Tallinn, Estonia, the maintenance of green areas and public transport streets is organized by Tallinn Municipal Engineering Services Department. Maintenance of streets with lower importance is under the responsibility of District governments. The actual maintenance procedures are carried out by contractors. Before every winter the maintenance equipment is sent for reviewing by the contractors (International Federation of Municipal Engineering, 2016).

In Sweden the costs of winter maintenance have been able to be lowered due to contract models taking the cost of readiness and emergency responses into consideration (International Federation of Municipal Engineering, 2016). In Stockholm, salt brushing was tested, and quality control was performed by quality reports by the contractor and spot checks by the city officials. Maintenance action thresholds and time limits were left out of the agreement. Instead the quality requirement was defined as “cycling must be safe around the year and slipperiness may not occur”. In Linköping, Sweden, the quality requirements were dropped out of the written contract, and the standards were agreed upon with continuous discussion. Threshold for snow is 1 cm and action time three hours. In future, thresholds will also be dropped out of the contract similar to Stockholm. In both cities, the prioritized snow brushing routes are maintained with route specific contracts covering the entire network. In Linköping, the other bikeways are maintained under areal contracts (Salermo, 2015). The contracts are made in five-year periods. “The contract period is designed to be long enough to make it worthwhile for the contractors to invest in new equipment, for example.” Contractors decide the starting times of maintenance themselves, but must inform the city whenever starting the maintenance. In Umeå the city center is maintained by the city itself. Other areas are maintained by contractors, starting with a three-year contract with a possibility for extension. Contractors must notify the city officials before the beginning of maintenance actions. Movements and performance are also traced with GPS-locators (Karhula, 2014). According to Sik and Granlund (2012), one way of improving winter maintenance is to have stricter quality requirements.

The city of Oulu, Finland, has divided the maintenance area into eight regions. Of these eight areas, four are managed by the city (TEKLI) itself. External contractors perform the maintenance of the remaining areas with four-year contracts. The contract dates are overlapped so that they do not expire simultaneously. The contractors start the maintenance independently, but the city might contact the contractor(s) separately if needed. Notifying the city about starting the maintenance is not necessary, but the quality of maintenance is controlled with inspections. The city officials and contractors meet monthly to discuss issues and feedback (Karhula, 2014).

In Finland, the roads under the administration of the Finnish Transport Agency are maintained with areal contracts. The ordering and tasks related to it are organized by regional Centres for Economic Development, Transport and the Environment (later as EDTE-Centres), according to instructions by the Finnish Transport Agency. Contractor takes care of the whole road network owned by the state in the contract area, and the main contractor may use subcontractors. The stock (vehicles and equipment) needed and to be used in maintenance are carefully described in contracts and already in tendering phase. The contract area, personnel and stock are inspected, and quality requirements are confirmed together with contractor. The quality is controlled with contractor reports and inspections by the regional manager (from EDTE-Centre), who also manages the maintenance ordering process. Furthermore, meetings with the contractor are arranged monthly, and reviews annually. If the maintenance does not fulfill the quality requirements, regional manager should communicate with the contractor about the issues. Sanctions should be given only if the quality does not improve even after notifying the contractor (Finnish Transport Agency, 2013).

As stated before, decreased injury treatment costs, increased health and other positive impacts and savings could be achieved by improving winter maintenance. In some locations, the budget of winter maintenance is still not increased, which possibly indicates a lack of knowledge about the benefits of improved maintenance or disbelief towards it, even though several studies have proven the positive impacts of it. According to Glavić et al. (2016), the problem here might be that the decision makers do not understand the costs and benefits of winter maintenance. They also say, that improved maintenance improves economic development and efficiency. There are many ways to improve winter maintenance, but sustainable changes happen through "a change in institutional culture".

2.3.6 Intelligent maintenance systems

The need for winter maintenance actions and decisions to start them have traditionally been based on visual observation. Weather forecasts have also been used to prepare for upcoming tasks. However, the ever-developing technology could be utilized to make winter maintenance more effective. In the 2000s the implementation of technology for decision making has been experimented, and slowly been taken into permanent use, which supports and can be integrated as a part of Intelligent Transportation System (ITS).

In the simplest form, the decision-making support systems consist of following parts: input data, functions and algorithms, output data. The parts may branch off to several components, containing various forms of information from several various sources. The most common components and layout of intelligent winter road maintenance management system is presented by Kociánová (2015) in Figure 23.

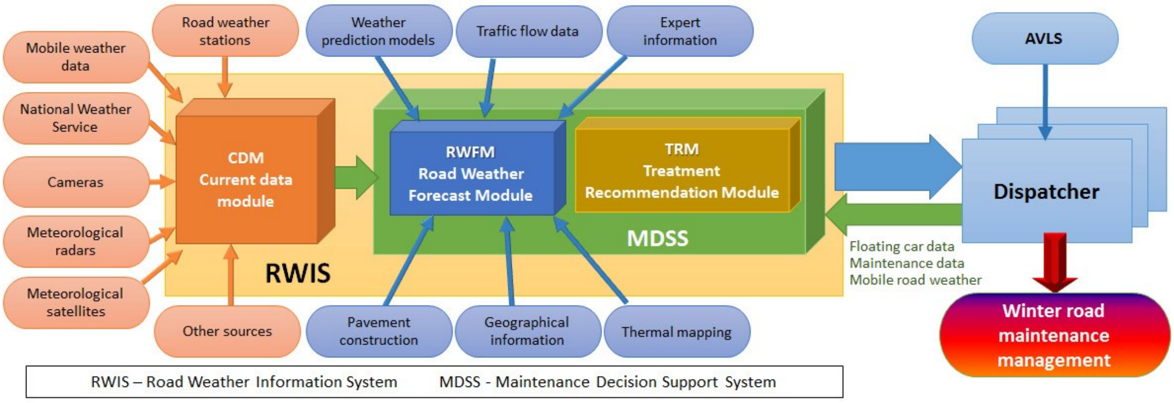


Figure 23 Layout and components of intelligent winter road maintenance management system (Kociánová, 2015)

"The aim of intelligent winter road maintenance management is to give the dispatcher and driver spreaders a set of intelligent tools that will help them optimize their work." Dispatcher is the "manager" of the system. It monitors the weather and road conditions continuously, and makes the decisions whether a maintenance action is needed and in which location. It also tells the user the proper maintenance method and recommended technology. The dispatcher also keeps record of the performed actions. However, the "driver is equally important, because he is responsible for quality of the actual performance of maintenance in the field" (Kociánová, 2015).

Maintenance vehicles should be equipped with intelligent technology, which communicates with the dispatcher. The "on-board electronic unit" informs the driver about routes and proper actions. It can even be used to adjust the amount of spread of de-icer or sand or such, and adjust the width of plowing. The vehicles should also have GPS- or other position tracking facilities, so that the dispatcher is aware of the location of the vehicle. This is also known as Automatic Vehicle Location System (AVLS). Combining this data, the system can store spatial data about maintenance (and additional information) for example on an online server, where for example maintenance history on a specific route or location can be viewed. Additional sensors can be installed to vehicles, measuring for example road conditions, humidity and temperature. This "mobile road weather data" can be utilized in several ways. Thermal mapping (TM) is a method for collecting data of road surface temperature and its variance. Data produced by mobile sensors may be used as an input data in road weather information system as well. This enables, for example, the adjustment of the amount of deicer spread according to specific location taking into consideration the forecasted weather, instead of static spreading. Sensors can also be used for supporting decision making, when installed on "normal" vehicles making observatory rides (Kociánová, 2015). They have also been installed on some "civilian" vehicles as well, for example buses and taxis for monitoring roadway conditions (Hirvonen, 2018a).

An essential part of the road weather information system (RWIS) is the data produced by road weather stations (RWS). They collect and transmit real time meteorological and pavement data automatically. RWSs usually measure such variables as air and pavement temperature, humidity, precipitation, wind speed and visibility, road surface condition, water film width, friction and freezing point. Also other variables can be measured, for example salt concentration. Conventional road sensors are embedded in the road surface, but lately also contactless, optical remote sensors have been developed and implemented. For example, in Sweden, a two-dimensional weather camera was taken into use in 2014, which used a normal camera and scanning features. RWSs can also be used to collect information to be used for informing the road users. RWS may be connected to variable message signs, warning the users about weakened road conditions. Even some deicer spreading systems have been installed, which are activated automatically, when the road conditions require such actions. Installing weather monitoring equipment (sensors) on vehicles turns them into "mobile road weather stations." Additional weather data sources include meteorological satellites and radars, weather service and other systems collecting data about the road weather. In future, intelligent "civilian" cars may also be producers of road weather data, providing dynamic real-time data on a more extensive scope around the road network (Kociánová, 2015). This data could be combined to navigation applications as well, providing information about the road weather on the planned route, and offering choices to avoid poor conditions.

"Dispatcher needs software support for proper and effective management of winter maintenance." Relevant and available data is collected by the RWIS-software, which acts as a decision-making support system in winter maintenance management. The system provides the user (dispatcher) with real-time and forecasted (road) weather and surface conditions, and also historical data. For the information to be read and understood more easily, the data may be displayed in maps, tables and graphs. Sophisticated RWISs may also suggest recommended winter maintenance actions. RWISs collect data from maintenance vehicles in action (AVLS) as well. Thereby performed maintenance actions may be linked to spatial data, mapping the operations of maintenance vehicles. The main objective of RWIS is to combine data from various sources, but it may also be equipped with forecasting module, to help planning and organizing proactive maintenance actions (Kociánová, 2015).

Being able to forecast the future road conditions is a key factor in proactive winter maintenance. Maintenance decision support system (MDSS) is a component of RWIS, which uses weather and road surface condition forecasts to formulate recommendations for appropriate winter maintenance actions. In another words, they "generate predictive outputs on the basis of specific inputs." MDSS consists of two main components: Road Weather Forecast Module (RWFM) and Treatment Recommendation Module (TRM). The RWF module collects data from CDM, and combines it with thermal mapping, geographical information, pavement construction, traffic flow data, weather prediction models and expert information, when possible. It should provide forecasts for various time terms: medium-term (two days) for preparation of drivers, vehicles and materials, and short-term for instant decision-making. Short-term forecasts enable the use of "selective approach" in winter maintenance. Maintenance can be focused on locations that need them, instead of going through the route despite it not needing maintenance actions. This would save resources, and thereby reduce costs through right scheduling of maintenance vehicle departures, and additionally improve the maintenance level on the whole operation area, as the vehicles may be appointed to the neediest locations first. The RWF should also be provided with GPS-specific data about winter maintenance methods performed, as for example chemical deicing affects the future road conditions and forecasts. The TRM then uses the data of current situation and performed maintenance events, combines it with weather forecast, and then formulates "treatment recommendations for winter maintenance operators." This is a highly helpful tool especially for operators with low experience (Kociánová, 2015).

Road Status Information (RSI) is a road weather information system, which was started in 2014 as a research project in Sweden in collaboration with Swedish Transport Ministry, automotive industry and universities. The main goal is to develop a platform, which uses vehicle data, which can be used to improve winter roads. The data collection happens via static road weather stations, and is complemented with dynamic road weather data produced by data collecting equipment connected to vehicles driving on roads (Figure 24). The input data includes such information as RWS-data, temperature, precipitation, mist, friction, weather forecasts, maintenance- and GIS-information. The RSI produces models, which are used by maintenance operators, contractors, officials and other such parties. With RSI, for example more effective and objective road status monitoring, dynamic traffic control, contract models and proactive maintenance can be developed (Karim, 2017). In addition, intelligent winter maintenance management system may be equipped with a tool for evaluating the costs and performance of winter maintenance.

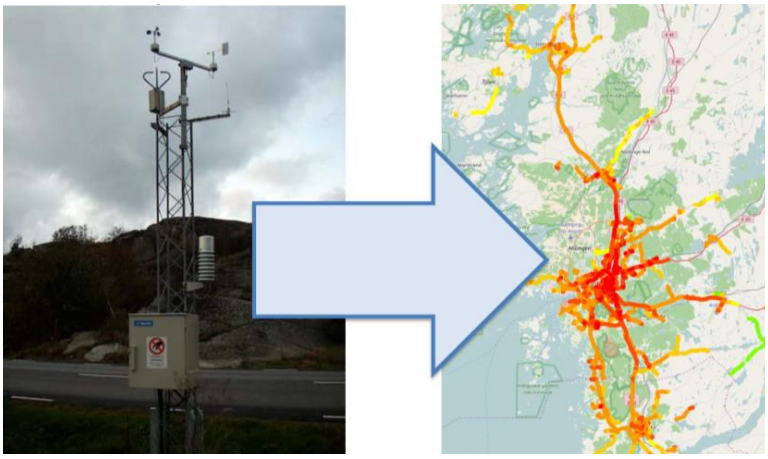


Figure 24 Transforming RWIS from static points to dynamic RWIS network (Karim, 2017)

Road State Monitoring System (ROSTMOS) is a project of Nordic Countries to develop a more comprehensive road information system. Countries involved in the project are Norway, Sweden, Finland, Denmark, Iceland and Germany. The original project took place between 2013 and 2016, and the follow-up project is scheduled from 2016 to 2018. Part of the project is an independent comparison study of different road weather monitoring systems and friction meters. Other objectives are to formulate uniform European standards for manufacturers of mobile sensors, development of maintenance decision support systems and road weather models and integration with intelligent transportation systems (Kärki, 2017).

3 Methodology

3.1 Research aim

As a part of this master’s thesis a study about the impacts of traffic environment, weather, road conditions and maintenance on cycling and pedestrian conditions is performed. The study is a part of a larger project, which aims to improve the pedestrian and cycling conditions. The project is initiated by Centre for Economic Development, Transport and the Environment of Southwest Finland. The study is located on the cycling and pedestrian paths of the road 110 (Uudenmaantie) between the city centers of Turku and Kaarina. The general aim of the project is to find methods to improve pedestrian and cycling conditions. In particular, the study aims to find answers to following research questions:

1. What kind of weather and road conditions are in the study location?
2. What factors affect cycling and pedestrian activity in the study area?
3. How can walking and cycling environment be improved for pedestrians and cyclists?
4. What kind of winter maintenance practices should be continued and developed in the study area?

The study methods include three parts: monitoring the weather and road conditions, traffic counting and survey.

3.1.1 Description of the study context

In Finland, the organization responsible for organizing the maintenance of the road is defined by law. Highways, which include Main roads Class I (valtatiet), Main roads class II (kantatiet), Regional roads (seututiet), Connecting roads (yhdystiet), are under responsibility of state government. The responsibility is appointed to Finnish Transport Agency and Regional Centres for Economic Development, Transport and the Environment. Adjacent sidewalks, cycleways and combined cycling and pedestrian paths are defined to be part of the highway (Finnish Transport Agency, 2016) (Edita Publishing Oy, 2005). Winter maintenance methods and standards of these roads are defined by Finnish Transport Agency.

The definition of street by Finnish laws is a bit looser: street area is defined by zoning. Organizing of winter maintenance of streets is under the responsibility of the municipality. However, some exceptions are defined. For example, if a sidewalk runs through a plot, the maintenance is under the responsibility of the plot owner (Edita Publishing Oy, 1999) (Edita Publishing Oy, 1978).

The study focuses on the combined cycling and pedestrian paths running along on both sides of the regional road 110, also known as Uudenmaantie, between the city centers of Turku and Kaarina (see Figure 25). In this segment, the road includes two motor vehicle lanes per direction. In some intersection areas the number of lanes is higher. The combined cycling and pedestrian paths are located on both sides of the road, on the outer side of the motor vehicle lanes. At the intersection with Hovirinnantie in Kaarina, the northern path is shared with motor vehicles for a segment of about 350 meters. At Piispanristi, the northern side path is shared with motor vehicles as well for a segment approximately 450 meters. Between the intersections of Uudenmaantie with Kaskentie and Hippoksentie, the combined pedestrian and cycling path is located only on the western side of the road. From the intersection with Hippoksentie until Itäinen Pitkäkatu combined pedestrian and cycling paths are found on both sides. From Itäinen Pitkäkatu -intersection towards Turku the eastern side is equipped with raised cycle track.

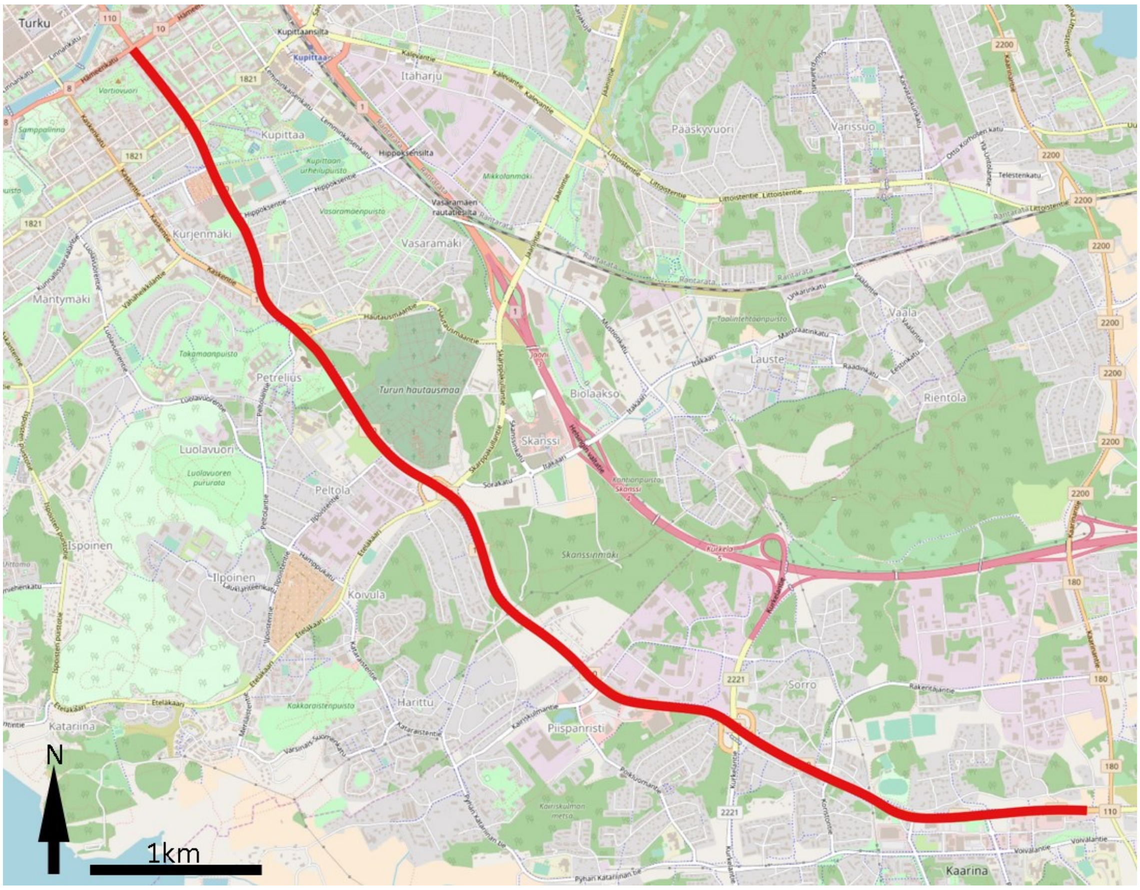


Figure 25 The study area (Road 110 "Uudenmaantie") on bright red. Modified from OpenStreetMap (2018)

Pedestrian and cycling traffic was counted 4.5.2015 (Monday) at Skarppakullantie intersection, near the cemetery. Based on the data collection on that day, during summer on average 744 cyclists ride past cross section. In winter time this number is 93 and the average on entire year 417. Average daily pedestrian traffic through the year is 85 pedestrians a day. On 24.5.2017 (Wednesday) the average bicycle traffic was 456, and average daily bicycle traffic in summer was 814. Based on the 6-hour pedestrian counting, the number of pedestrians increased by 15,4 percent compared to 2015, which would mean a daily average traffic of approximately 98 pedestrians a day. (Centre for Economic Development, Transport and the Environment of Southwest Finland, 2017)

In the region of Southwestern Finland, the amount of accidents per capita in 2011 was approximately 11 percent higher than in Finland on average. Nearly half of fatal accidents in urban areas happened to cyclists, pedestrians or moped drivers (Klang et al. 2012). In Turku, the number of cycling accidents leading to injury is the highest among Finnish cities. Most of the accidents concentrate in the city center area and entrance highways. The most typical form of accident is a collision with a car when a cyclist is crossing the road on bike path extension. Most frequent reasons for this is that one of the parties was not following the traffic rules, and that the car driver did not notice the cyclist. Methods listed for improving traffic safety include decreasing speed differences, traffic education and intersection improvements (The City of Turku, 2017).

3.1.2 Winter maintenance requirements in study area

The study area is the combined cycling and walking paths of the regional road 110, so the organizing of winter maintenance is under the responsibility of Finnish Transport Agency and Centre for Economic Development, Transport and the Environment, and the maintenance methods and requirements are defined in quality requirements document by Finnish Transport Agency. The contract area containing the study area belongs to Destia (Destia, 2017). On this specific road segment, maintenance is performed by a subcontractor, Tankkipojat Oy (Nikkanen, 2017).

The maintenance class of the cycling and pedestrian paths is K1 and the quality requirements are defined in the "Winter maintenance quality requirements" by Finnish Transport Agency (2015): "On the cycling and pedestrian paths, snowiness, unevenness and slipperiness must not hinder safe moving. The maintenance level of paths must be such, that cyclists and pedestrians do not relocate themselves on the roadway. During the night, after 22 h, the quality may be lower, but the surface must be safe for moving, and the maintenance actions must be performed before 6 h." (Finnish Transport Agency, 2015)

The quality requirements for class K1 during 06 to 22 h are:

- "Maintenance preformed before the beginning of traffic, by 6:00 h
- Paths next to main roads are plowed right after the main road
- The maximum amount of loose snow during snowfall is 3 cm (1.5 cm for slush). Plowing must be in progress when half of the maximum amount of snow has fallen (in this case 1.5 cm). The maximum amount of snow must not exceed during the snowfall, or procedure time. Procedure time is defined as the time between the end of snowfall and finishing of plowing. When the snowfall ends after 22 h, the paths must be cleared before 6 h. The maximum amount of snow on path in the night (22-06 h) is 8 cm.
- Procedure time for snow removal is 3 hours. (Must be cleared within three hours after the snowfall has ended.)
- Over 2 cm deep steep or otherwise hindering unevenness may not occur
- Enough friction for safe walking and cycling
- Procedure time for gritting is 2 hours
- Public transport stop connections are maintained similar to rest of the walking and cycling path
- Crosswalks are maintained so that the surface is safe to use" (Finnish Transport Agency, 2015)

Other specifications considering the snowiness and evenness of the paths include:

- "Snow depth is measured as an average of the cross section of the path
- On class K1 paths, snow depth must not be over 8 cm during 22-06 h
- Temporarily it is allowed to leave a maximum amount of 1.5 cm dry snow unplowed, hindering wet snow or slush must not be left unplowed
- During exceptional snow storms, the maximum snow depths may exceed
- On a walking and cycling path locating immediately next to roadway, the hard-compressed snow layer must be kept horizontal, so that the cyclists do not drift onto the driveway

- During spring the softening compressed snow layer should be removed to further cycling. The softening layer of compressed snow must be kept under 2 cm thick
- Only indented, grading plowing blade may be used in plowing and evening. However, even or rubber blade may be used in slush removal, when it comes off the path surface” (Finnish Transport Agency, 2015).

Specifications considering the friction of the paths:

- “Gritting is performed according to conditions with an adequate amount on the whole path or only on specific locations such as deep hills and crosswalks.
- The maximum grain size of the material is 6 mm, and the material is approved by the ordering organization.
- The material may not harm tires. Salt may not be used on walking and cycling paths for friction control.
- On zoned areas the whole width of the path is gritted.
- Outside zoned areas it may be separately agreed to leave an ungritted section on the side of the path for sleds” (Finnish Transport Agency, 2015).

Finnish Transport Agency has defined methods for determining the friction of the road. These methods include driving touch, visual observation, friction measuring, and road condition description presented in Table 4 with descriptions of different friction values.

Table 4 Friction values (Finnish Transport Agency, 2015)

Friction value	0.00-0.14	0.15-0.19	0.20-0.24	0.25-0.29	0.30-0.44	0.45-1.00
Description	wet ice, **extremely slippery**	icy, **slippery**	smooth compressed snow, **satisfactory winter road condition**	antiskid ice and compressed snow, **good winter road condition**	bare and wet, **antiskid road condition**	bare and dry, **antiskid road condition**

Friction meter must be approved by Finnish Transport Agency. It must be based on deceleration or some other technology approved by the ordering organization. The meters must be calibrated each winter season. The calibration is done so that the meter shows value 0.29 on harsh hard compressed snow layer, in a mild subzero temperature (around -5 -Celsius degrees) (Finnish Transport Agency, 2015). The friction values presented in the table are not physical friction coefficients, even though they are scaled somewhat similarly. In addition, the friction measuring by deceleration is capable of measuring friction only on single locations instead of the whole route (Hirvonen, 2018a) (Noukka & Nummelin, 2015).

Maintenance of stairs:

- “Winter maintenance of stairs is performed so that the use of stairs is safe.
- Procedure time for snow removal and friction control for stairs is same than walking and cycling path adjacent to the stairs.
- Uneven hard compressed layer of snow on stairs must be evened or removed without delay.
- Snow must not be stored under the hand rails of stairs even temporarily.
- Stairs without winter maintenance must be access restricted with a gate” (Finnish Transport Agency, 2015).

Miscellaneous requirements:

- "Individual crosswalks with possible islands, which aren't adjacent to walking and cycling paths, are maintained similar to crosswalks with islands of walking and cycling paths, so that the surface is safe to use.
- Operation of buttons of traffic signals must be unchallengeable and safe. The front of the buttons is maintained as the walking and cycling paths.
- Snow piles are relocated before they cause traffic problems.
- During spring the melting snow piles are removed without delay.
- Melting water damages are prevented by relocating benches and opening the ice blockages of the sewers.
- The freezing problems of underpasses must be prevented also during springtime" (Finnish Transport Agency, 2015).

3.1.3 Current winter maintenance in the study area

The winter maintenance on combined walking and cycling paths of regional road 110 between Turku and Kaarina is performed by a subcontractor named Tankkipojat Oy. The maintenance methods are based on the quality requirements by Finnish Transport Agency. For a more detailed information about winter maintenance on the area, the manager of Tankkipojat Oy (Nygren) was interviewed.

The vehicles used on study segment include body steered multi-function machine LM-Trac 680 (Figure 26), two-axle truck with grit spreader and an under blade (Figure 28), and a pick-up car with plow (Figure 27) for underpasses. The plows used with the LM-Truck and pick-up are equipped with indented edges, with a width of 3.00 or 3.20 meters. The grit used is 3-6 mm and 4-8 mm in grain size. Gritting the study segments (both sides, 2x10 km) takes roughly 2 m^3 of grit. Estimated duration of operation of the study segment takes approximately two to three hours. The costs of the winter maintenance in total are determined by the contract, in this section about 1500€ per week. (Nygren, 2018a)


Figure 26 (left) LM-Trac used for maintenance in study area (Nygren, 2018a)
Figure 27 (middle) Pick-up used for maintenance in study area (Nygren, 2018a)
Figure 28 (right) Two-axle truck used for maintenance in study area (Tankkipojat Oy, 2018)

The grit used was bought in bulk some years ago to last for about three or four winters, and it is stored in Urusvuori deposit. Smaller amount of salt, which is used on roadways, is also stored there. The salt supplier is Destia, who has a larger salt storage in Paimio (Nygren, 2018a).

The contract obligates the contractor to drive through the whole route. However, maintenance actions are performed only if needed. The route is driven through in a logical order without diversions, starting from a "sensible" point. The stock and workforce are in operation whenever needed, sometimes even around the clock. The utilization rate is close to hundred. There is no situation where the available vehicles should be moving but are not, i.e. the stock is in use whenever needed. The vehicles are dispatched based on alarms by Destia weather service, which has "assumingly worked decently". Performance is tracked with Fluent-Kunto application, which is a smart phone application, collecting GPS-linked data about performed maintenance actions. The Fluent-Kunto application is a part of Kunto ERP-system. Intelligent winter maintenance management system is not in use. In springtime, the grit is removed with an "open" brush. However, the use of it is slow and the cleaning result is not the best possible. Also, the trees make the cleaning difficult, as the branches are hanging over the path. They also drop a lot of leaves on the path, and the roots are pushing through the asphalt (Nikkanen, 2017) (Nygren, 2018a).

3.2 Experiment setup

Data is collected about weather, road condition, traffic and experiences and opinions. Data on weather and road condition is produced by optical sensors, and some of the variables are comparable to data produced by weather companies. Traffic data is collected with traffic counters and manual counting. The positioning of the data collecting devices is presented in Figure 29 The experiences and opinions of road users is collected with a survey.

3.2.1 Sensors for monitoring weather and road conditions

To answer the first study question (about weather and road conditions), two sensors are used to monitor the road condition. Continuous data is produced by a static sensor, STARWIS (abbreviation of the words Stationary Road Weather Information Sensor) (Figure 30). The device requires constant electric current. The easiest location for installation was the intersection of Piispanristi (roads Uudenmaantie and Kairiskulmantie), where the electricity could be taken from traffic signaling control unit. Next to the electricity source a tall pole was put up, so that the sensor could monitor the road from above enough (4.6 to 5.6 meters). The other sensor used in this study is a mobile one, and it monitors the same variables as the static one. This MARWIS (abbreviation of the words Mobile Advanced Road Weather Information Sensor) is mounted to a vehicle and used for monitoring routes.

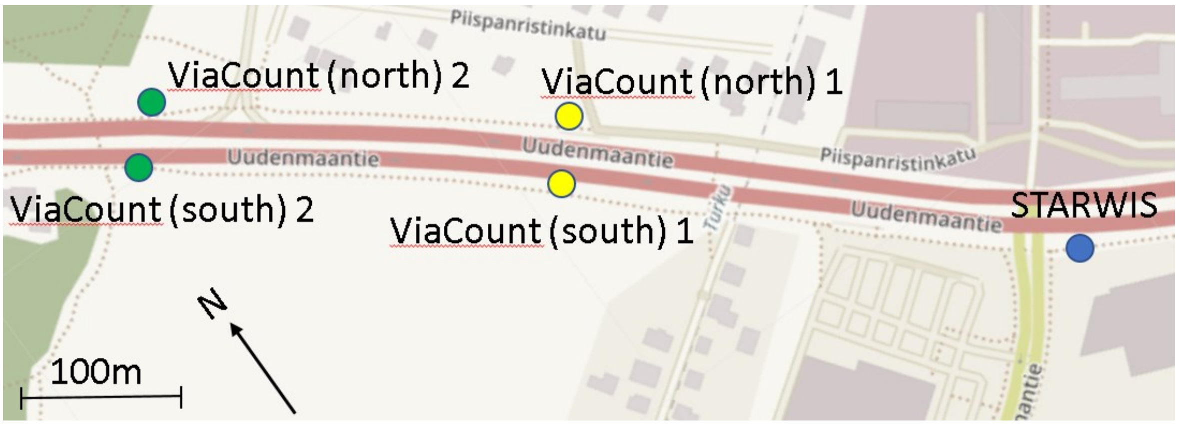


Figure 29 Locations of STARWIS-weather sensor and the traffic counters. Modified from OpenStreetMap (2018)

The functioning of both sensors is based on same technology: infrared measuring. Both devices include “four emitting and two receiving diodes capturing the reflecting behavior of the road surface at varying wave lengths.” Due to different materials having different spectral properties, they influence waves differently. The transformations in the wave reflections can thereby connected to material properties causing the transformation. (Lufft, 2017)

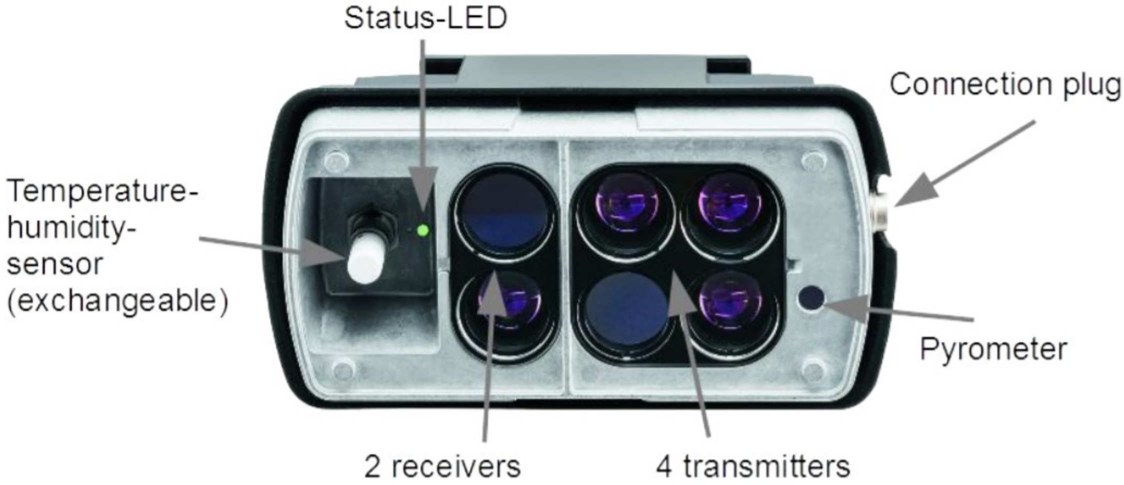


Figure 30 The MARWIS/STARWIS sensor (Lufft, 2017)

The sensors collect data about following variables:

- **Road surface temperature**. Measuring is performed optically “with a non-invasive pyrometer.” The measuring range is between -40 ºC and +70 ºC. The resolution is 0.1 K, and the accuracy at 0 ºC is 0.8 K. Sampling rate is less than one second.
- **Ambient temperature**. The air temperature is measured only by MARWIS, with a NTC-thermistor on the side of the device. Temperatures between -40 ºC and + 70 ºC are measurable. The measurement resolution in 0.1 K, and the accuracy in the speed of 40 km/h is ± 0,5 ºC. Sampling is rate one second.
- **Relative humidity**. Measured only by MARWIS. The measuring is performed with a capacitive principle, with the measuring range from 0 to 100 percent, resolution of 0.1 percent, and an accuracy of 3 percent (at 40 km/h). Sampling rate is one second.
- **Dew point temperature** is not measured actively. As instead, it is calculated from air temperature and humidity. The measuring range is between -50 ºC and +60 ºC. The resolution is 0.1 K and sampling rate 1 second.
- **Relative humidity at road temperature** is calculated passively on the basis of the absolute humidity and the road temperature. Measuring range is between 0 and 100 percent, with a resolution of 0.1 percent and a sampling rate of 1 second.
- **Water film height** indicates the amount of liquid water on the road. It “is measured with a non-invasive optical spectroscopy.” Measuring range is from 0 to 6 mm, with resolution of 0,1 µm. The accuracy is ± 10 percent on sleek ground. Sampling rate is 100 Hz, meaning 100 measurements per second.

- **Ice percentage** is determined on the basis of data from optical spectroscopy. Measurng range is from 0 to 100 percent, with the resolution of 1 percent unit, and sampling rate of 10 Hz
- **Friction**. "The friction value of the device indicates to which degree the maximum possible grip of a specific road is reached, respectively how much it has been reduced by ambient conditions. Therefore, identical friction values on different road surfaces mean different grip." The friction value scale is from 0.1 to 1.0, where higher values indicate a better grip. Resolution for friction is 0.01. Sampling rate is 10 Hz.
- **Road condition** is determined using road surface temperature, ice percentage and water film height as input data. The output e.g. the road condition types include "dry, damp, wet, ice-covered, snow-/ice-covered, chemical wetness, water+ice, snow-covered and undefined". This is, however, based on logic coding classes, and is under constant development, meaning that changing for example water film height thresholds can change the condition class. The road condition is updated ten times a second (sampling rate of 10 Hz).

Some models are also capable of determining the freezing temperature and deicer density. However, such sensors were not used in this study.

3.2.2 Traffic volume counting

For evaluating the factors affecting cycling and pedestrian activity, two VIACount II traffic counting devices were installed to the study area: one on the northern side walking and cycling path of Uudenmaantie, one on the southern side. The device uses Doppler radar for vehicle detection. Per each detection, following data is collected: timestamp, speed, direction and length of the vehicle. With the VIAGraph software, for example vehicle classifications (based on vehicle length) and time interval of the output data can be defined by the user. The software then exports the data into Excel format, where the results are presented in table- and graph form. Data can be presented about average speeds, maximum speeds, speed percentage points, vehicle amounts, result tables, speed distribution, vehicle distribution and raw data.

Traffic volume counting was performed to link numerical traffic data to numerical weather sensor data. These traffic counters are designed for vehicle counting instead of pedestrians and cyclists. For this reason, during the changing of the batteries of the traffic counters, traffic amounts were counted visually to determine how well the device counts non-motorized traffic. It was already known, that the device counts bicycles better than pedestrians, since the bicycles have a metal frame, which reflects the radar rays better than organic material and clothes.

The devices were installed on Monday 22.1.2018 on both sides of the road 110. Both devices were installed approximately 1 meter above ground level. However, the data they produced was not 100 percent accurate (when comparing manual counting and the data by device from the same period), and some modifications were made after recommendations on Tuesday 30.1. The parameter "Radar distance range" was changed from 6 % to 16 % on both devices. In addition, the northern device was installed higher, approximately 2 meters above ground level, and the radar was set to angle, counting the passing traffic downwards.

These adjustments however, did not help reaching the desired accuracy in the number of counted bicycles and pedestrians, so the devices were installed to poles nearer (ViaCount North/South 2 in Figure 29) to the road edge on Wednesday 7.2. Comparing the data by the device to manual counting on Wednesday 7.2. showed, that the devices were counting the amounts more accurately.

3.2.3 User survey

To complement the data about which factors have an influence on walking and cycling activity, a survey was carried out. They survey is expected to provide verbal and stated preference -type of data, which is not collectable via sensors and traffic counters. The survey was performed as a Webropol survey. The questions included different question sets depending on the answerer filling the form as a pedestrian or a cyclist. However, the question contents were consistent with each other regardless of the answerer type (cyclist/pedestrian). For cyclists, a separate question set was given for the members of cycling club of Turku (Turun polkupyöräilijät ry).

The survey was performed by handing out answering forms at the study location during the counting of the cycling and pedestrian traffic, and electronically on the internet. To promote the survey, a bulletin was compiled, which was published on the web pages of the Centre for Economic Development, Transport and the Environment of Southwestern Finland, and sent to local newspapers. The survey was also promoted in several cycling -related Facebook-groups. Handing out survey forms on site was not continued after study week 1 due to low success rate, but also due to the vast amount of answers received via Webropol.

The web version of the survey form begins with the question about the perspective the answerer answers with: pedestrian or cyclist. Depending on the answer, question set with either walking or cycling related questions is given to the answerer to fill. These questions are fairly similar to each other. The questions collect information about walking and cycling habits and characteristics, opinions about the impact of winter, experiences about the state and maintenance in the study area, and opinions and suggestions about improvements. Specialized question set was given to the members of Turku cycling club, to collect information about how well they feel they can perform their agenda. This information is not crucial for the study, but helps in mapping the state of cycling politics in Turku region. The answerers were also asked how they found out about the survey. Finally, the answerers could give open comments. The survey questions are listed in Appendix 1.

3.2.4 Presentation of results

The results are presented in graphic form for better visual and conceptual understanding. Traffic amounts are projected next to different weather and road condition variables to observe relationships between the variables.

The weather sensor results were exported to Excel-format, where the conditions were presented on 10-minute interval on average. From these values, hourly averages were calculated. Data was analyzed with one week at a time, which resulted in one Excel-file per week, a total of 6 files.

Traffic data was exported to Excel format as well. Data was analyzed on hourly interval in one-week periods which resulted in six Excel-files in total. These one-hour average values of weather sensor and traffic data were combined to a single Excel-file per week, resulting in a total of 6 Excel-files from the whole six-week study period, each one containing the hourly average values of weather sensor and traffic data.

However, it was noticed that daily averages provide more continuous and usable form of data. Thereby a single Excel-file was formed, where daily averages of weather sensor and traffic data are listed from the six-week study period.

In the results, the traffic and sensor data are presented in graphs with daily averages. The graph of traffic amounts contains two plots, one of which presents the total amount of pedestrians and cyclists of both sides and both directions combined. The other plot presents an estimated correct traffic amount. This number is formed using Formula 1.

$$n_{\mathrm{est}} = n_{\mathrm{device}} \times a_{\mathrm{corr}} \qquad (1)$$

where n_{est} = Estimated total number of pedestrians and cyclists
n_{device} = The number of pedestrians and cyclists according to the device
a_{corr} = A week- and device-specific correction factor

The correction factor is determined using Formula 2.

$$a_{\mathrm{corr}} = n_{\mathrm{man}} \div n_{\mathrm{device}} \qquad (2)$$

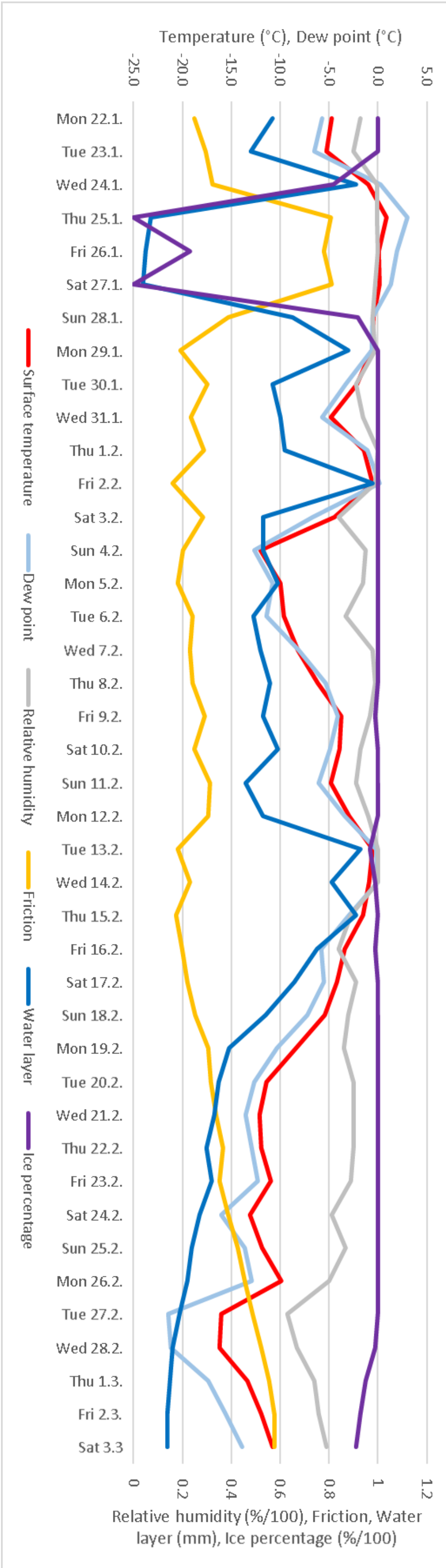
where a_{corr} = A week- and device-specific correction factor
n_{man} = Total number of pedestrians and cyclists counted manually in a specific time
n_{device}= Total number of pedestrians and cyclists counted by the device in a specific time

Adjustments of the devices and settings are taken into account in determining the correction factor. For weekly graphs with hourly average values, see Appendix 2.

The survey question answers are presented according to question type. Questions, where answers are given from pre-defined options, are presented graphically to demonstrate the proportions of answers. Open text field answers were read through and answers related to the topic were taken into account.

4 Results

4.1 Traffic and weather data



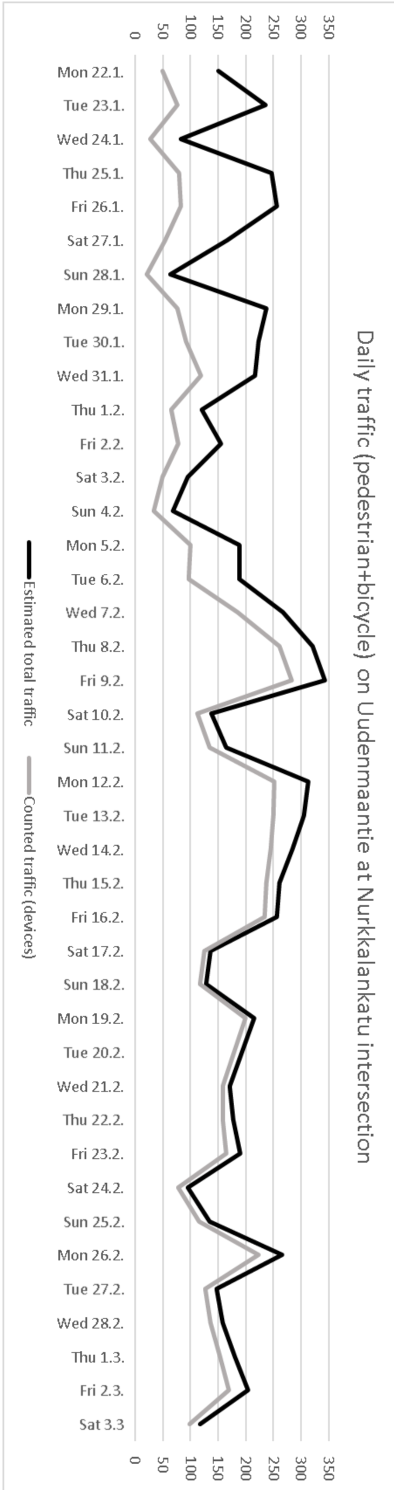


Figure 31 (left) Daily average weather data
Figure 32 (right) Daily average pedestrian and cyclist traffic

The STARWIS and traffic data are presented in
Figure 31 and Figure 32 on previous page. The values of STARWIS data are presented on different axles, depending on the variable. Values on the left axle include temperature values (as Celsius degrees) for road surface temperature and dew point. On the right side, values for relative humidity, friction, water layer width and ice percentage are shown. Percent values of relative humidity and ice coverage have been divided by 100, so that they can be showed on the same scale as friction and water layer width (which is presented as millimeters). Figure 32 shows traffic volume daily. The days in the graphs are lined so that the variables in different graphs can be compared easily.

4.1.1 Study week 1 (22.1.2018-28.1.2018)


Figure 33 (left) Weather and road conditions on Monday 22.1.2018 11:47, also showing the first location of the southern ViaCount -device (ViaCount (south) 1) (Peltonen, 2018).
Figure 34 (right) Weather and road conditions near the eastern end of the study area on Thursday 25.1.2018 (Hirvonen, 2018b).

MARWIS measurement of the study area was performed on Thursday 25.1.2018 between 13:39 and 14:18. Air temperature on the day before went from below 0 degrees Celsius to above zero. In addition, it was snowing. (Foreca, 2018) On Thursday, the temperature was constantly above 0 ºC and the snow had melted completely. The friction value on the whole study segment was somewhat constant 0.82 and ice percentage 0. There was slight variance in the road surface temperature, varying from 2.22 to 5.94 ºC. Water layer depth varied between 0 and 0,49mm. Based on photos, there were also some puddles in some locations. The lowest friction value measured was 0.75 and the highest 0.82. The system labelled the road condition on most locations as icy, and in few locations snowy.

Manual counting of traffic was performed on Monday 22.1.2018 from 16:00 to 18:00. During this period, manual counting on northern side gave a result of 29 cyclists and 9 pedestrians, resulting in a total number of 38. The device counted a total number of 8 pedestrians or cyclists. On southern side there was 14 cyclists and 12 pedestrians, thereby a total of 26. The device counted 9.

Following maintenance was performed:
On Wednesday 24.1.2018. between 7:00 and 15:30: plowing of snow.
On Thursday 25.1.2018 between 4:45 and 10:45: gritting (Nygren, 2018b).

4.1.2 Study week 2 (29.1.2018-4.2.2018)

Figure 35 (left) Weather and road conditions on Tuesday 30.1.2018 14:50 also showing the first location of the northern ViaCount -device (ViaCount (north) 1). In the first study week (22.1.-29.1.2018) the device was installed lower. On the second week it was installed approximately 2,00m above ground (Peltonen, 2018).
Figure 36 (right) Weather and road conditions on Uudenmaantie bridge over Eteläkaari on 2.2.2018 6:48. Heavy snowing on previous day and in the night before (Hirvonen, 2018b).

In study week 2, MARWIS measurement of the study area was performed twice: on Tuesday 30.1.2018 between 17:49 and 18:16, and on Friday 2.2.2018 between 6:48 and 7:16. Air temperature on Monday went from slightly above 0 degrees Celsius to below zero, no rain or snowfall (Foreca, 2018). On Tuesday, the road surface temperature varied between -0.23 and 2.36 degrees Celsius. Average road surface temperature was 0.72 ºC. The friction value varied from 0.52 to 0.82, and on average it was 0.61. Maximum width of water layer was 0.32 mm, and minimum 0 mm. Besides two single measurements, the ice percentage was 100 on the whole study area. The paths were covered in light layer of snow. The cycling and walking conditions were generally good.

The second MARWIS measurement of the week was performed on Friday 2.2.2018 between 6:48 and 7:16. On Thursday the air temperature went from mild subzero temperature to slightly above zero (approximately +0.5 ºC). There was heavy snowfall. On Friday the air temperature was fairly constant +1 ºC until six in the evening, when it went below zero. On Friday the air temperature was slightly above 0 ºC until six in the evening. (Foreca, 2018) Road surface temperature was above 0 ºC on the whole study area, between+1.48 to +3.01 ºC. Water layer depth varied between 0 and 1.08mm. The lowest friction value measured was 0.32, and the highest 0.82. Besides a single measuring point, the ice percentage on study area was 0. The system labelled the road condition as wet throughout the entire study area.

Manual counting of traffic was performed on Tuesday 30.1.2018 from 15:00 to 16:30. During this period, manual counting on northern side gave a result of 20 cyclists and 7 pedestrians, resulting in a total number of 27. The device counted a total number of 10 pedestrians or cyclists. On southern side there was 18 cyclists and 3 pedestrians, thereby a total of 21. The device counted 8.

Following maintenance was performed:
On Thursday 1.2.2018 between 4:45 and 12:45: plowing of snow.
On Thursday 1.2.2018 between 15:30 and 19:00: plowing of snow.

On Friday 2.2.2018 between 7:00 and 16:00: plowing of snow.
On Sunday 4.2.2018 between 11:30 and 19:00: plowing of snow. (Nygren, 2018b)

4.1.3 Study week 3 (5.2.2018-11.2.2018)

Figure 37 Weather and road conditions on Wednesday 7.2.2018 13:59, also showing the second location of the northern ViaCount -device (ViaCount (north) 2) (Peltonen, 2018).

Manual counting of traffic was perforemed on Wednesday 7.2.2018 from 15:00 to 18:00. During this period, manual counting on northern side gave a result of 31 cyclists and 12 pedestrians, resulting in a total number of 43. The device counted a total number of 39 pedestrians or cyclists. On southern side there was 28 cyclists and 13 pedestrians, thereby a total of 41. The device counted 29.

Following maintenance was performed:
On Sunday 11.2.2018 between 13:45 and 21:45: plowing of snow (Nygren, 2018b).

4.1.4 Study week 4 (12.2.2018-18.2.2018)


Figure 38 (left) Weather and road conditions on Wednesday 14.2.2018 14:05, also showing the second location of the southern ViaCount -device (ViaCount (south) 2) (Peltonen, 2018).
Figure 39 (right) Weather and road conditions on Friday 16.2.2018 13:16 at Uudenmaantie (Hirvonen, 2018b).

MARWIS measurement of the study area was performed on Friday 16.2.2018 between 13:05 and 13:39. Air temperature on the day before was around 0 degrees Celsius, going through several freeze-thaw cycles between -0.4 ºC and +0.2 ºC, until dropping to approximately -5 ºC by midnight. On Friday, the air temperature stayed below 0 ºC the entire day. (Foreca, 2018) Highest road surface temperature measured was -1.55 ºC, and lowest -5.91 ºC. The friction varied between 0.19 and 0.82, with an average value of 0.29. Ice percentage on the area (besides three single points with value 0) varied between 59 and 100 percent, with an average of 81.8 percent. Minimum water layer depth (besides three single points with value 0) measured was 0.4 mm, and the maximum 0.95 mm. The system labelled the road condition mostly as snowy+icy, with some locations as snowy, icy or dry.

Manual counting of traffic was performed on Wednesday 14.2.2018 from 15:00 to 18:00. During this period, manual counting on northern side gave a result of 31 cyclists and 11 pedestrians, resulting in a total number of 43. The device counted a total number of 43 pedestrians or cyclists. On southern side there was 23 cyclists and 7 pedestrians, thereby a total of 30. The device counted 25.

Following maintenance was performed:
On Tuesday 13.2.2018 between 15:45 and 00:15: plowing of snow.
On Friday 16.2.2018 between 16:00 and 18:30: gritting (Nygren, 2018b).

4.1.5 Study week 5 (19.2.2018-25.2.2018)

Figure 40 Weather and road conditions on Thursday 22.2.2018 14:13 (ViaCount (north) 2) (Peltonen, 2018).

Manual counting of traffic was performed on Thursday 22.2.2018 from 15:30 to 18:30. During this period, manual counting on northern side gave a result of 19 cyclists and 6 pedestrians, resulting in a total number of 25. The device counted a total number of 25 pedestrians or cyclists. On southern side there was 7 cyclists and 9 pedestrians, thereby a total of 16. The device counted 15.

No reported maintenance actions on study week 5 (19.2. – 25.2.2018.) (Nygren, 2018b)

4.1.6 Study week 6 (26.2.2018-4.3.2018)

Figure 41 Weather and road conditions on Thursday 1.3.2018 13:57 (ViaCount (south) 2) (Peltonen, 2018).

Manual counting of traffic was perforemed on Thursday 1.3.2018 from 15:00 to 17:50. During this period, manual counting on northern side gave a result of 22 cyclists and 12 pedestrians, resulting in a total number of 34. The device counted a total number of 29 pedestrians or cyclists. On southern side there was 15 cyclists and 11 pedestrians, thereby a total of 26. The device counted 19.

No reported maintenance actions on study week 6 (26.2. – 4.3.2018.) (Nygren, 2018b)

In addition, three MARWIS measurements were performed after the study period on 14.3.2018 between 7:46 and 8:23, 16.3.2018 between 13:14 and 13:44, 22.3.2018 between 8:31 and 8:58. The results of these measurements are not presented or studied here, as they were not performed during the study period, and cannot be linked to STARWIS and traffic data.

4.2 User survey results

A total of 347 people answered the survey. Of these answerers, six answered twice to answer as both cyclist and pedestrian. Thereby a total of 353 responses was received.

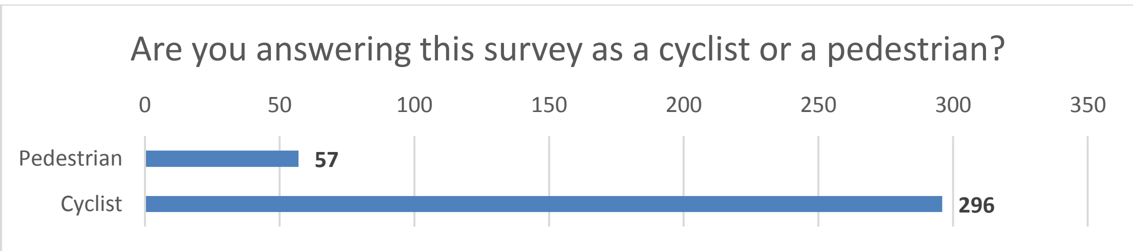


Figure 42 Number of survey answers given per perspective

Of the respondents, 222 found out about the survey on social media, 96 on newspaper or internet article of the paper, 12 heard from an acquaintance, 9 on the web pages of Centre for Economic Development, Transport and the Environment, 6 on somewhere else in internet, 4 via e-mail and two answers were given on paper at study location during traffic counting.

4.2.1 Pedestrians

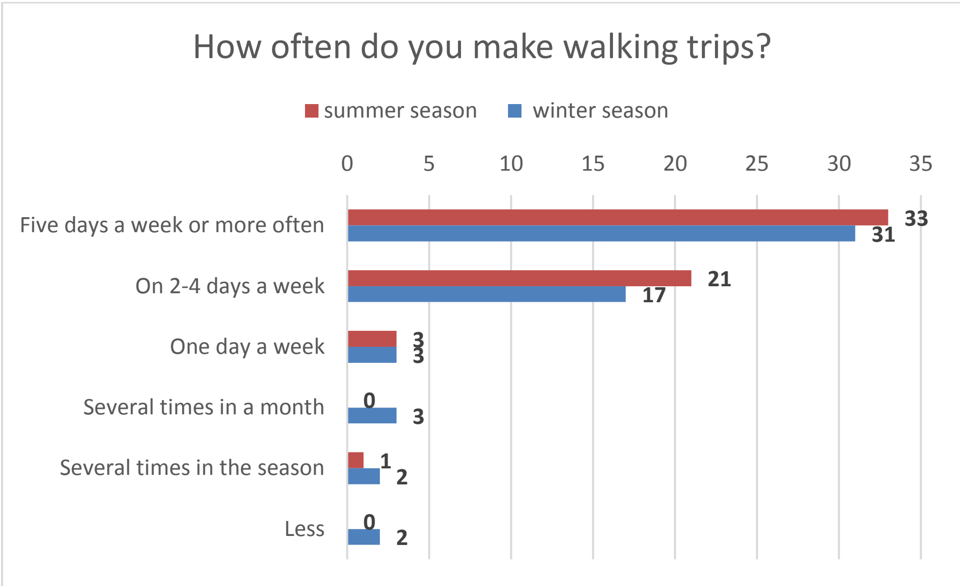


Figure 43 Walking frequency of pedestrians

In summer season, the minimum distance of a walking trip was 1km, maximum 50 km, average 4.66 km, median 3 km and standard deviation 6.55 km.

In winter season, the minimum distance of a walking trip was 0 km, maximum 57 km, average 4.91km, median value 3 km and standard deviation 7.75 km.

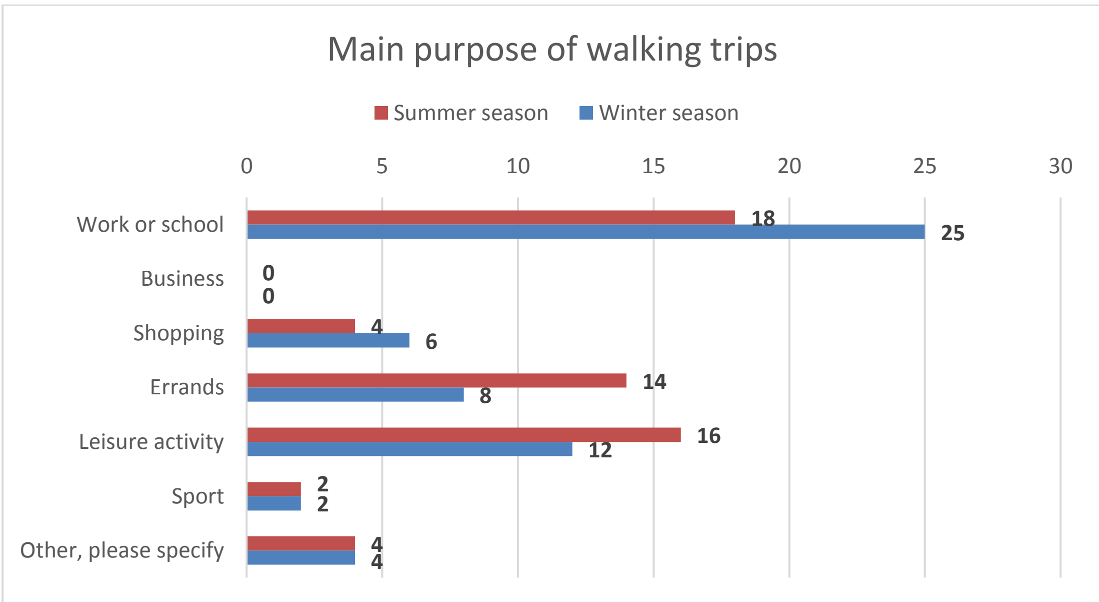


Figure 44 Purpose of walking trips

Of option "Other, please specify", three stated "walking the dog" and one stated "Several of the above", both seasons.

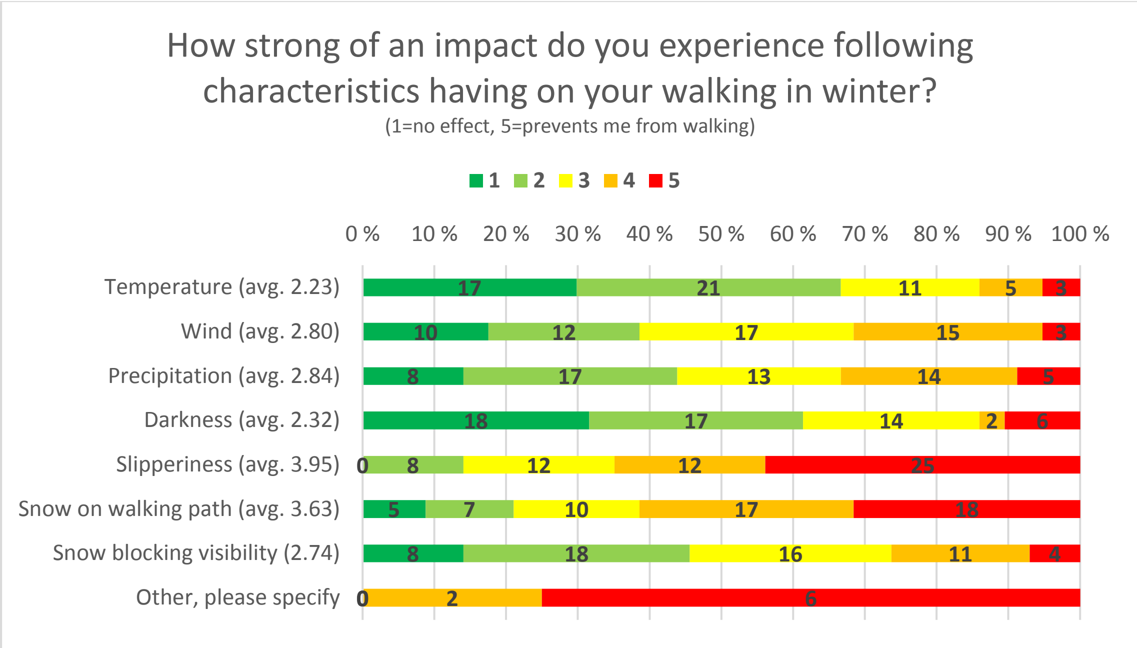


Figure 45 Impact of different factors on walking

"Other, please specify" -answers:
One mention of "Snow piles plowed onto walking paths from bus stops" with value 4.
One mention of "Slush following salting" with value 4.
One mention of "Using too much salt" with value 5.
One mention of "Sidewalks are not plowed" with value 5.
One mention of "Snow or ice storm" with value 5.
One mention of "Ice" with value 5.
One mention of "Cyclists riding without lights" with value 5.
One mention of "Gritting, snow barriers, slush and water puddles" with value 5.

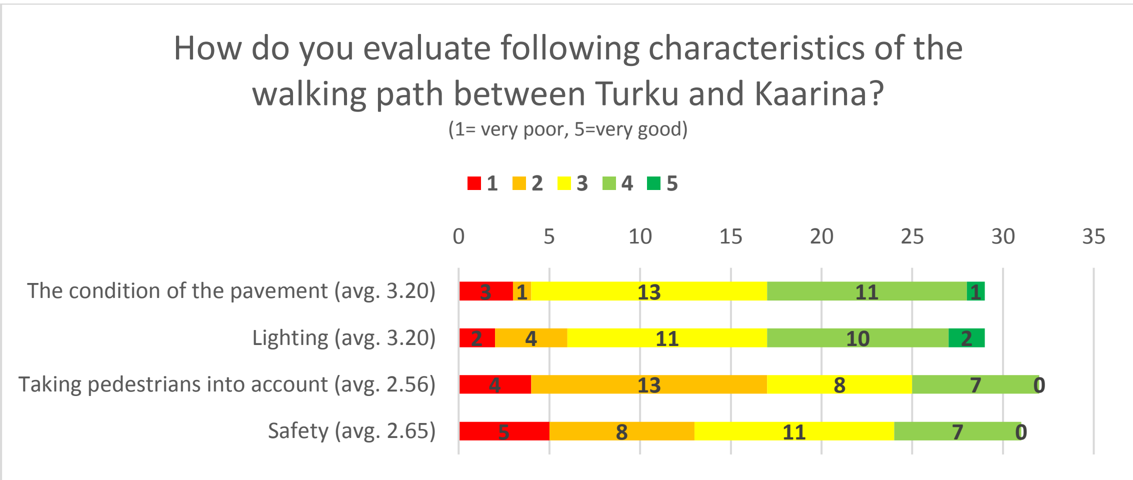


Figure 46 Evaluation of the traffic environment of the study area by pedestrians

Average values were counted using only the answers of those who did not answer "Don't know".

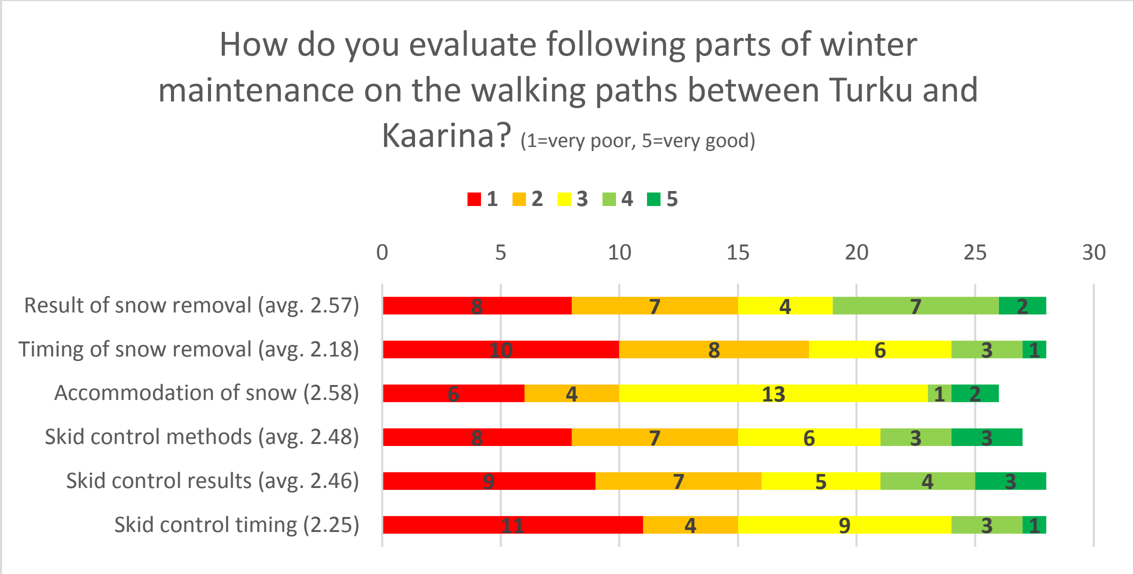


Figure 47 Evaluation of the winter maintenance in study area by pedestrians

Average values were counted using only the answers of those who did not answer “Don’t know”.

45 pedestrians (78.9 %) would develop walking conditions in winter with different snow removal methods, such as snow blowers and brushes. 29 (50.9 %) would use salt and/or other skid control methods. Other answers included faster and better plowing, heated streets, replacing salt with other methods, separation of traffic modes, intelligent management system, snow storage.

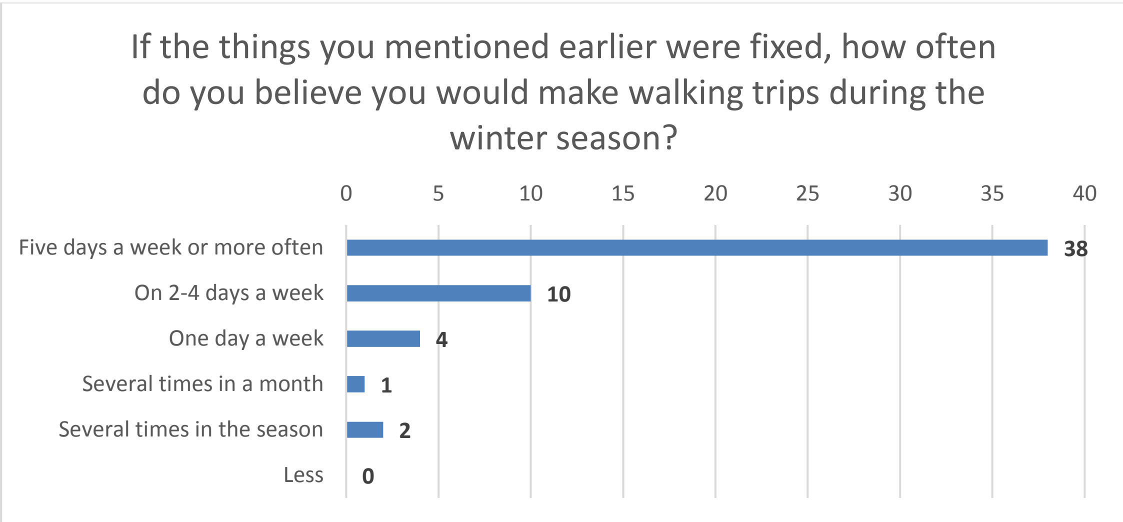


Figure 48 Evaluated walking frequency after improvements

Additionally, many pedestrians mentioned faster or better snow and slush removal, skid control, better maintenance overall, separation of traffic modes, accommodation of snow, decreasing amount of salt used, prioritization and improved lighting to increase walking.

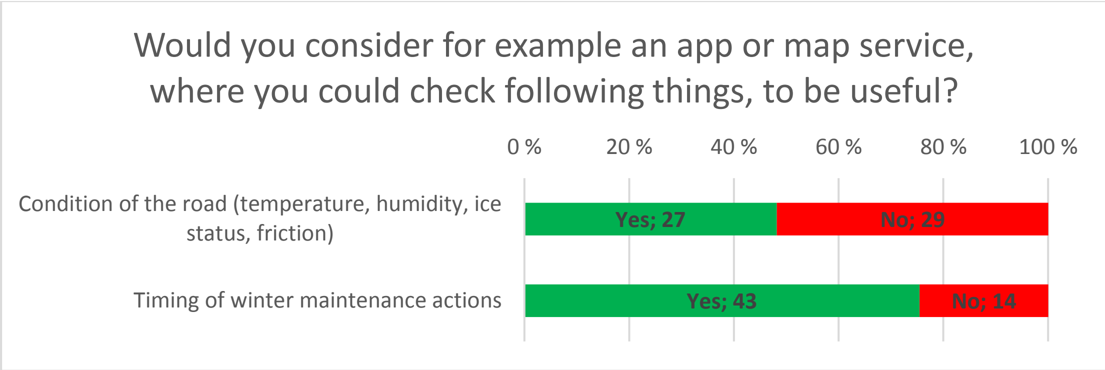


Figure 49 Opinions of pedestrians on information services

30 (52.6 %) answerers believe that if such system was available, they would walk more, 27 (47.4 %) believe it would have no effect on their walking frequency. No-one said they would walk less.

4.2.2 Cyclists

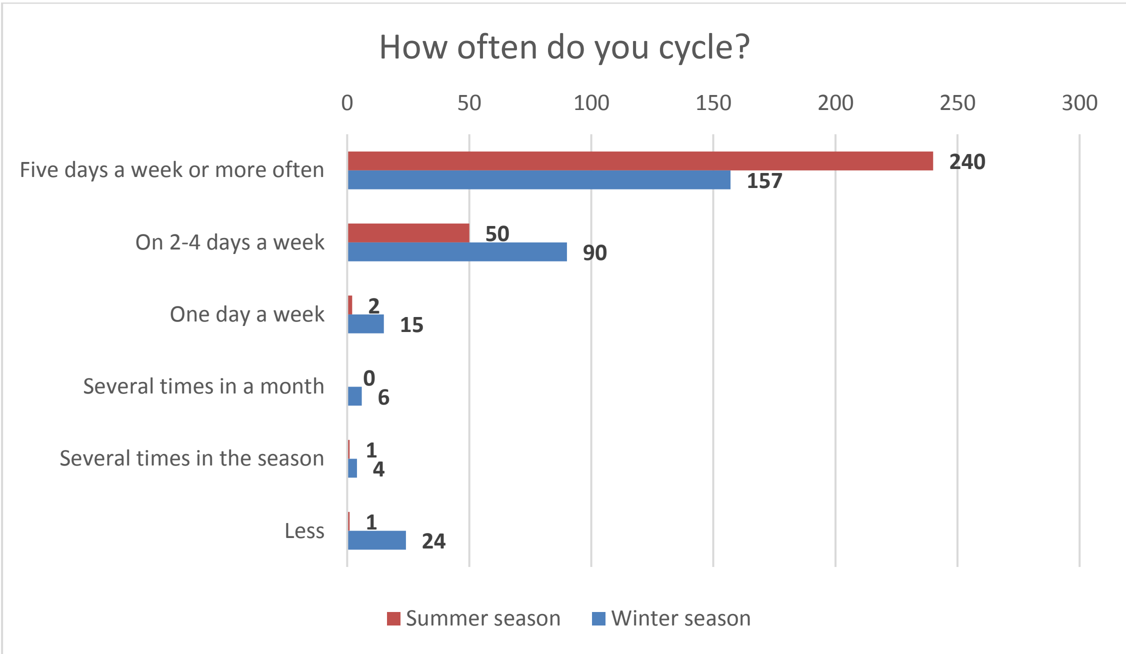


Figure 50 Cycling frequency of cyclists

In summer season, the minimum value of a cycling trip was 2 km, maximum 100 km, average 13.41 km, median 9 km, standard deviation 15.31 km.

In the winter season, the minimum value of a cycling trip was 0 km, maximum 100 km, average 9.82 km, median 7 km, standard deviation 11.91 km.

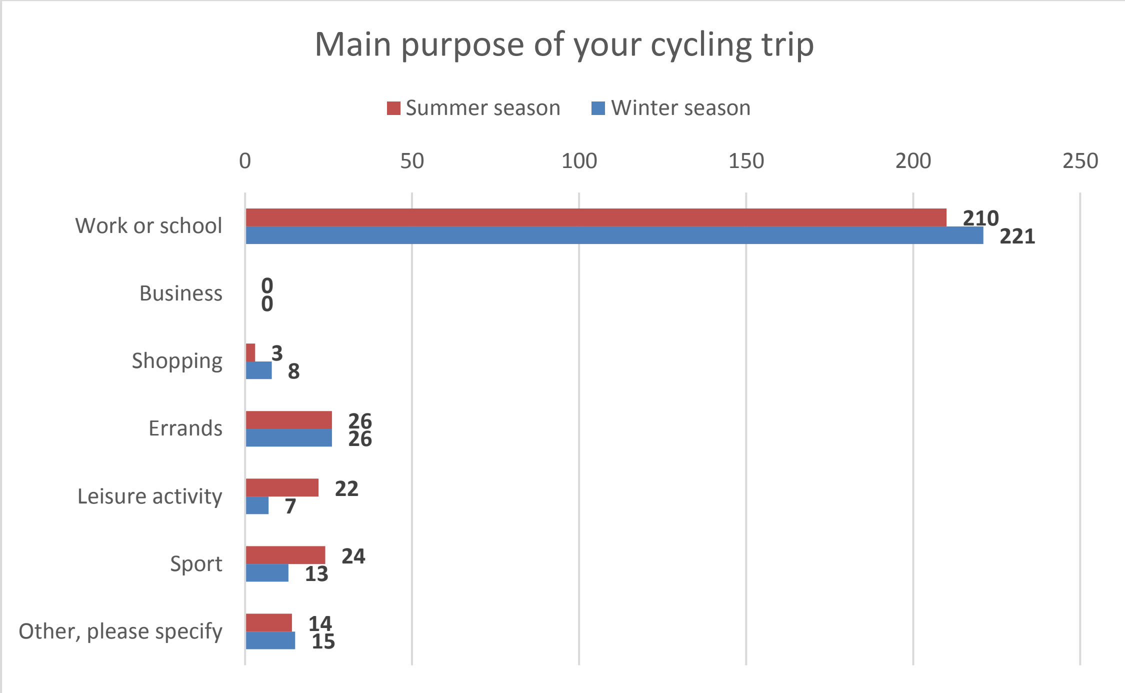


Figure 51 Purpose of cycling trips

Of option “Other, please specify”, nine stated “several of above” in summer.

Of option Other, please specify, seven stated “several of above” and 5 stated “I do not cycle in winter.”

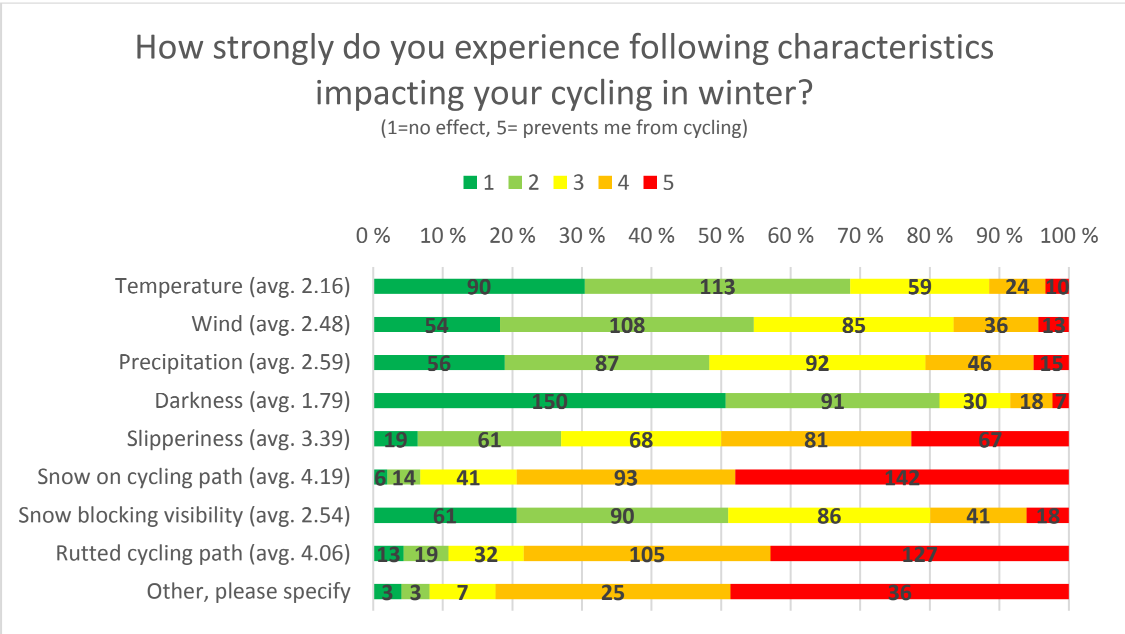


Figure 52 Impact of different factors on cycling

Other, please specify answers:
One mention of “Freezing of bike or -parts” with value 2.
One mention of “Pedestrians without reflectors” with value 2.
One mention of “Negative impacts of salt” with value 2.

Three mentions of “Parked cars,” of which one with value 3 and two with value 4.
Two mentions of “Pedestrians on cycling paths” of which one with value 3 and one with value 4
Seven mentions of “Carelessness of car drivers”, of which three with value 3, one with value 4 and three with value 5.
Two mentions of “Busy people”, of which one with value 3 and one with value 4
Ten mentions of “Snowbanks caused by plows and other plowing hindrances”, of which one with value 3, two with value 4 and seven with value 5.
Twenty-one mentions of “Poor or uneven removal of snow or slush”, of which seven with value 4 and fourteen with value 5.
Twelve mentions of “Sand” or “Gravel” or “Grit”, of which four with value 4, eight with value 5.
One mention of “Poor lighting” with value 4.
Two mentions of “Salt”, of which one with value 4 and one with value 5.
Two mentions of “Unawareness and irregularity of winter maintenance on route” with value 4.
Three mentions of “Lack of (safe) cycling paths” with value 3.
One mention of “High price of winter tires” with value 5.

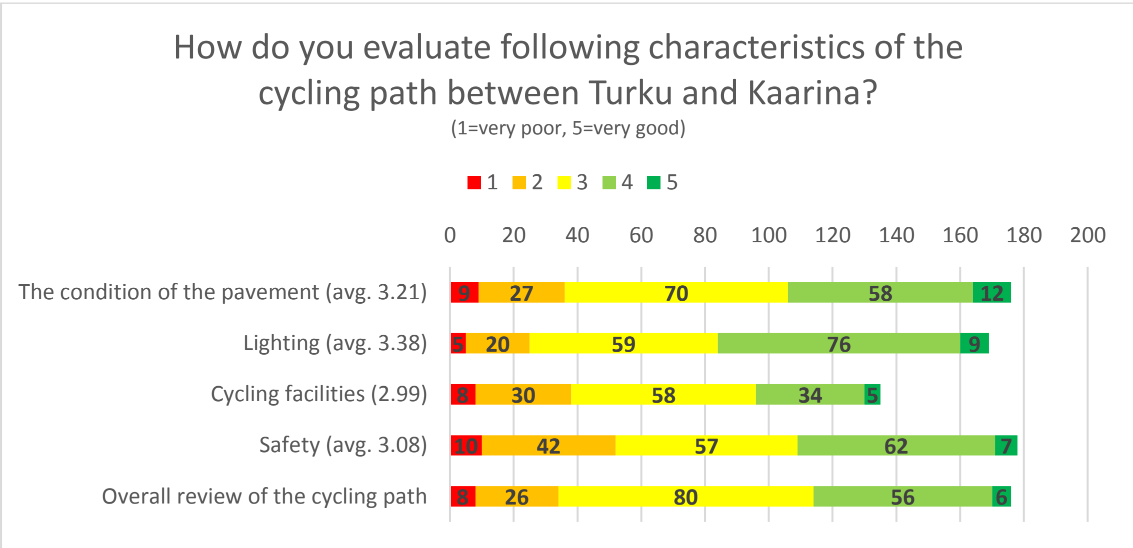


Figure 53 Evaluation of the traffic environment of the study area by cyclists

Average values were counted using only the answers of those who did not answer “Don’t know”.

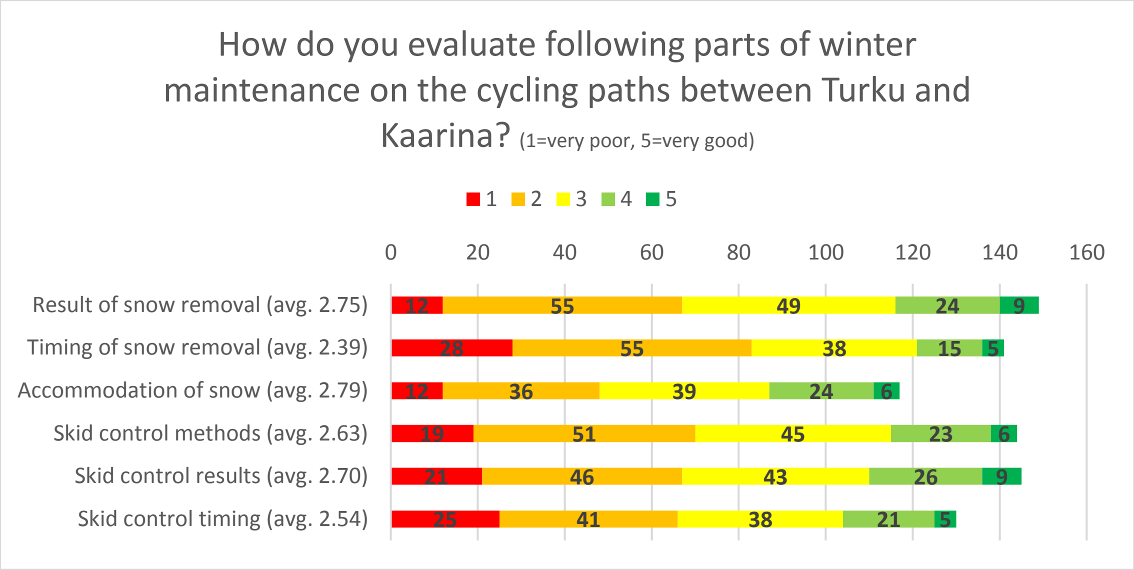


Figure 54 Evaluation of the winter maintenance in study area by cyclists

Overall average of winter maintenance on study section: 2,62

246 cyclists (83.1 %) would develop winter cycling conditions with different snow removal methods, such as snow blowers and brushes. 127 (42.9 %) would use salt and/or other skid control methods. Most frequent mentions in open answers were continuous/better/enforced maintenance, especially snow removal, timing of the maintenance, reducing the use of grit, reducing the use of salt, separation of traffic modes, prioritization.

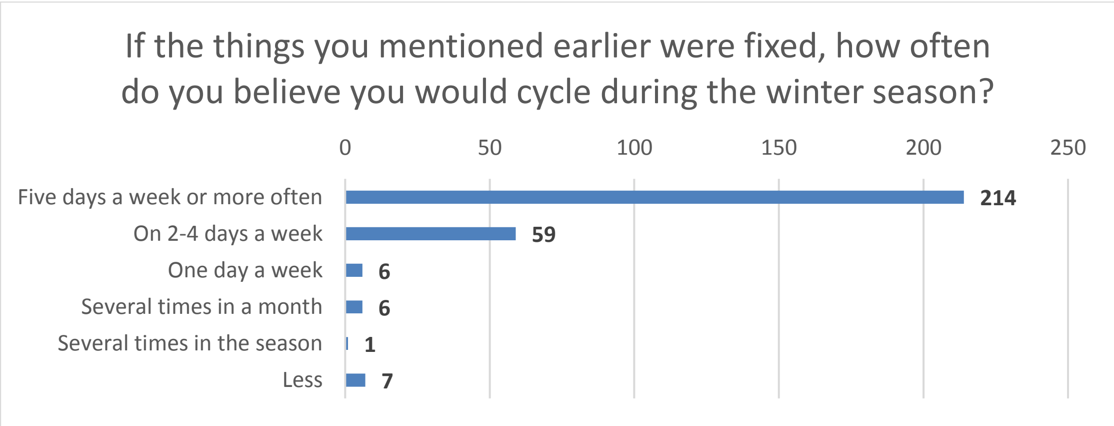


Figure 55 Evaluated cycling frequency after improvements

Additionally, the most frequent mentions for increasing cycling included removal of snow and slush earlier and more often, continuous and better maintenance, clearing snow plowed from roadways onto cycling paths, better design of cycling paths, better skid control, reducing the use of grit, more continuous cycling network, adequate salting, reliability and information about the road condition, separation of traffic modes, salt brushing, more continuous maintenance and prioritization.

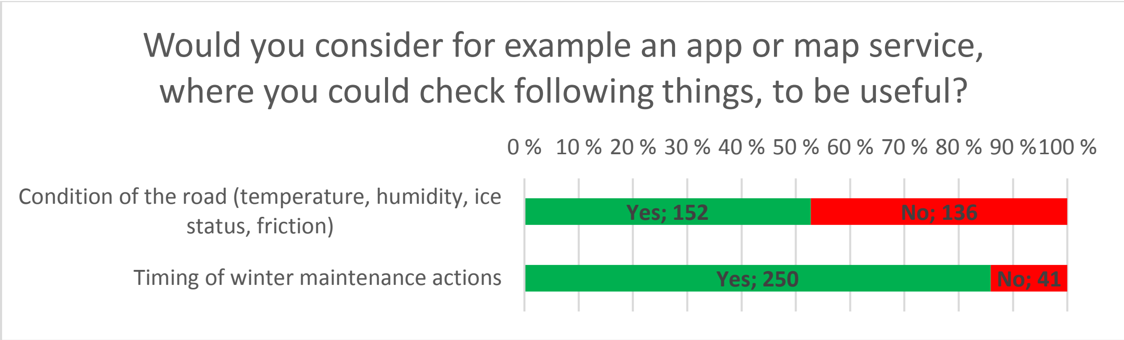


Figure 56 Opinions of cyclists on information services

160 (54.42 %) answerers believe, that if such system was available, they would cycle more, 132 (44.90 %) believe it would have no effect on their cycling frequency. Two answerers (0.68 %) said they would cycle less.

The last actual question of the survey was presented only to those who said they are a member of Turku cycling association TurPo ry. Of 296 cyclists, 31 (10.47 %) were members of the association.

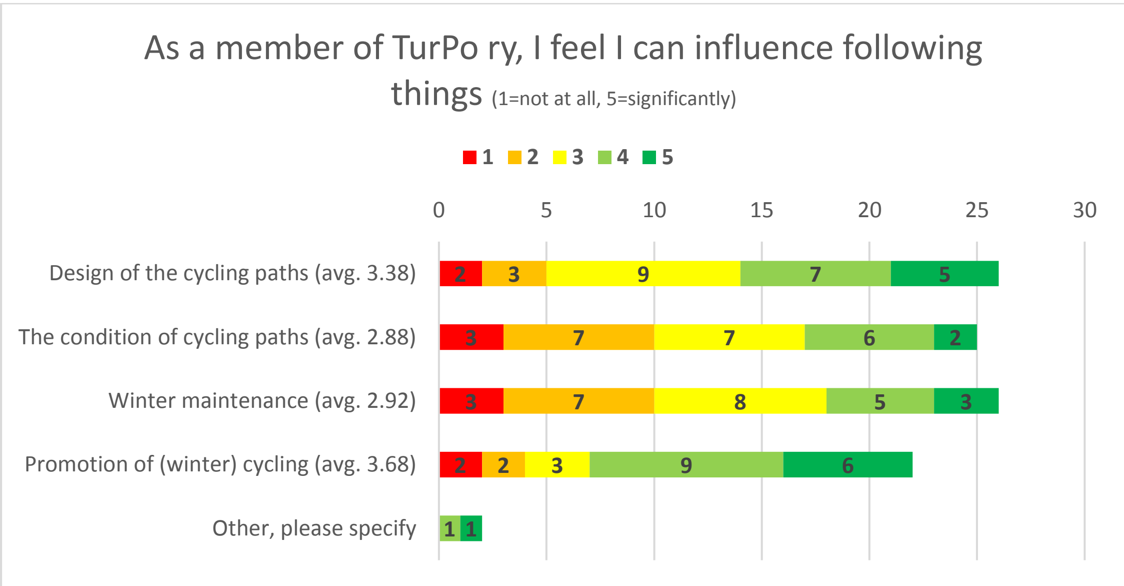


Figure 57 Influencing possibilities of Turku cycling association members

One mention of “Attitudes of local people” with value 4.
One mention of “Promoting cycling in general, for example city bikes, bicycle parking etc.” with value 5.

On open comments section, most frequent answers included positive feedback for salt brushing test route in Turku, strong opinions against salt, prioritization topics, need for attitude change.

5 Discussion

5.1 Discussion of findings

The first research question considered the weather and road conditions in the study location. Data about temperature, relative humidity, dew point temperature, water film height, ice percentage, friction and pedestrian cycling traffic data was collected on Uudenmaantie (road 110) between Turku and Kaarina between January 22nd and March 4th.

The weather data collection produced a significant amount of detailed data about the road condition during the study period. In Figure 31, where the results are shown, some internecine correlations can be found. Variables such as dew point, humidity and temperature are naturally connected, but for example the graphs of water layer and friction seem to be mirror images of each other in specific value ranges. In subzero temperatures, water layer width also seems to correlate with road surface temperature and dew point to some extent.

Determining the impacts of various factors on walking and cycling activity was to answer the second research question. These results are presented in a simplified form in Table 5. The traffic data collection experienced some difficulties during the first two study weeks. The counters were installed as close to the STARWIS-sensor as possible. However, the counters could only be attached to poles, which located slightly too far away from the road edge. The first attempt to fix the problem was to install the northern counter higher, and set the radar pointing downwards, so it would count pedestrians and cyclists from above. The measurement parameters of the southern counter were also changed to achieve more accurate results. As these methods did not help reaching the desired accuracy, the devices moved further away from the STARWIS to poles closer to the pedestrian and cycling paths. In the new locations the counters reached an acceptable level of accuracy. The effect of different observation location on actual traffic amount was considered minimal, as there were no significant feeding connections on either side.

Especially the results of traffic counting from 7.2.2018 onwards may be considered fairly reliable, as the difference between n_{device} and n_{man} decreased significantly. Traffic data prior to this date is less accurate, as the difference between n_{device} and n_{man} is much greater. However, it does show the alternation of traffic amount within a week, which can be used for interpreting the impact of weather and road conditions on walking and cycling levels. Long term comparison between for example the plus degrees with bare road surface of the first week and low temperatures with snow/ice covered roads of the last week may not be done completely reliably.

Of sensor variables, ice percentage was fairly constant 100 % from Tue 30.1.2018 to Wed 28.2.2018, after which it decreased slightly. The increase in temperature during Tue 23.1. and Wed 24.1. resulted in melting of snow and ice, which dropped the ice percentage to zero. A significant drop in traffic can be seen on Wed 24.1. when the snow and ice re melted approximately halfway through. Ice percentage increased back to 100 during the weekend of 27.1.-28.1., so the impact of snow percentage increasing on traffic is difficult to determine, as the traffic amounts drop during the weekends anyways. However, the drop-in traffic amount during 27.1.-28.1., when the ice percentage is still increasing, seems to be more notable than on other weekends. This would indicate, that the ice percentage does not have a major impact on traffic amounts, but changes in ice percentage have a decreasing effect on pedestrian and cycling traffic. As the percentage was almost constantly 100, not much can be said about the equivalence of results with previous studies. When the road was clear and dry, the estimated traffic was not higher than on snow/ice covered road. However, the drops in traffic on Wed 24.1. and Thu 1.2.2018 are probably explained with snowfall on the same day, which would be in line with previous studies about the impacts of snow and ice on road on pedestrian and cycling activity.

The friction value was somewhere between 0.2 and 0.3 between Monday 29.1.2018 and Sunday 18.2.2018, after which it steadily increased to approximately 0,6 by Saturday 3.3.2018. It was also noticed, that the lowest friction values appeared when there were changes in temperature near 0 ºC. Even though the friction values are not entirely corresponding with those of defined by winter maintenance quality requirements, they provide comparable data about the condition of the road. Correlation between pedestrian and cycling traffic and friction is weak. The friction value was the highest (0.8) during Thu 25.1.-Sat 27.1., when the asphalt was snow and ice free. From Mon 29.1. to Mon 19.2. friction value stayed between 0.18 and 0.35. During this period there were significant changes in traffic. After Mon 19.2. friction value began to increase slowly, but steady. During this time the amount of pedestrian and cycling traffic went through steep in- and decreases. Development of friction could be estimated with weather forecast models, so that the set requirements for friction value levels could be met by applying correct maintenance methods. Friction does not seem to have a major impact on traffic, but possibly, if friction was continuously kept on a high level with maintenance, more savvy and uncertain pedestrians and cyclists would feel safe using the paths, and the number of pedestrians and cyclists could be increased.

It is doubtful, that relative humidity on road surface affects walking and cycling activity directly. Exception is, when relative humidity reaches 100 %, which basically means rain- or snowfall. From Wed 24.1. to Mon 29.1. was approximately 100 the entire period, but the traffic activity decreased only on Wed 24.1. On Thu 1.2. a steep drop can be seen in traffic. That day relative humidity was on average 100 %, and also heavy snowfall was reported. This event indicates, that precipitation has a strong impact on walking and cycling activity. It is unclear, how strongly the form of precipitation impacts the mode choice. "How strong would the impact have been if the same amount of precipitation would come down as liquid water," since water does not pile onto road surface the way snow does, making the moving on foot or by bike more difficult. Nevertheless, the relationship between precipitation and traffic activity is similar to those observed in previous studies. In this study, the phenomenon was stronger than for example in study by Liu, Susilo & Karlström (2015). However, the finding in this study is based on a small number of observations.

In subzero temperatures, water layer width followed the progress of temperature to some extent: as the trend of temperature was decreasing, so was the water layer width, and vice versa. Between Thu 25.1. and Sat 27.1., when temperature went above zero, and snow and ice had melted away, the water layer was close to 0 mm, indicating that the road surface was dry, in another words: in a good condition.

Temperature seems to be the only variable, which has a clear correlation with pedestrian and cycling activity. If the general direction of temperature during the week has been increasing, like during Mon 5.2.-Fri 9.2., traffic has been increasing as well. From Wed 14.2. the general trend in temperature has been towards colder, as in traffic. Even daily changes can be seen: From Mon 26.2. to Tue 27.2. temperature drops sharply, as does traffic. The next day temperature stays the same, and traffic stays somewhat same as well. Towards Fri 2.3.

temperature rises, and so does the number of pedestrians and cyclists. As most of the traffic on the study area consisted of cyclists, the results are similar to study by Liu, Susilo & Karlströn (2015).

In addition, a survey about pedestrian and cycling conditions was organized, to compliment the numerical data with experience- and opinion-based data to find more reliable and extensive answers for the research question determining the impacts of different factors on walking and cycling habits, and to be considered in formation of recommendations. Firstly, the user survey results revealed, that winter decreases the number of trips made on both modes. However, the change was more noticeable among cyclists. It was also noticed, that the average length of cycling trip decreased, while for walking trips it increased. This may suggest, walking replaces some of the cycling trips during winter. These findings mean, that winter has a stronger impact on cycling than on walking.

Survey answers show, that pedestrians did not consider temperature to have such a strong impact on their walking habits (average 2.23). Wind was experienced stronger (2.80). Precipitation was considered to have a more significant impact (2.84). Pedestrians evaluated slipperiness (3.95) and snow on walking path (3.63) to be the most significant barriers. Pavement condition and lighting on study site were evaluated slightly better than OK (both 3.20). Taking pedestrians into account was evaluated only 2.56 and safety 2.65. Separation of traffic modes was often mentioned as a way to improve walking environment. Pedestrians were not too happy with the maintenance on study paths. Timing of snow removal scored the lowest (2.18). Faster snow removal was also frequently mentioned in open question answers. The highest score was given to Accommodation of snow: 2.58, which also clearly needs improvement. According to the answerers, improving the path and maintenance and information about the route condition and maintenance would increase the amount of walking trips in winter.

Similar to pedestrians, cyclists evaluated temperature having a low impact on their cycling frequency, even slightly lower (average 2.16). Wind (2.48), precipitation (2.59) and slipperiness (3.39) were also evaluated as lower barriers than by pedestrians. However, snow on cycling path was given a considerably higher value (4.19). Rutted cycling path was also evaluated as a significant barrier (4.06). Open answers often mentioned poor snow removal and snowbanks left by plows. In study area, pavement condition (average 3.21), lighting (3.38) and safety (3.08) were rated more positively by cyclists than pedestrians. Cyclists also felt that they have been taken better into account, as they rated cycling facilities 2.99. Methods to improve cycling environment included better design of cycling paths, more continuous cycling network and similar to pedestrians, separation of traffic modes. Cyclists also rated the winter maintenance on study area more positively than pedestrians. Despite giving every maintenance sector a higher score, on average cyclists were also not too satisfied with the maintenance on site, as the highest rating is 2.79 (given to accommodation of snow). Majority of cyclists would develop winter maintenance with different snow removal methods, and better maintenance overall. The use of grit and salt both received mixed opinions. However, opinions about salt and especially the salt brushing test route received surprisingly positive feedback. Attitudes towards the use of salt also changed to a more positive direction in Helsinki, when the results of salt brushing became apparent (The City of Helsinki, 2016). Cyclists would also like to receive information about the route condition and maintenance, and 54.42 percent believe availability of such information would make them cycle more.

44.90 percent said it would not change their cycling activity. 0.68 percent stated that they would cycle less.

In the first study week, on Wed 24.1. it was snowing from midnight to two in the afternoon, and from nine in the evening until two in the night the form of precipitation was water. Plowing was performed between 7:00 and 15:30. Gritting was performed on the next day between 4:45 and 10:45. In the second study week, on Thu 1.2. there was heavy snowing: the snow depth increased by approximately by 10 cm. The snowing had begun already in the night. (Foreca, 2018). Plowing was performed between 4:45 and 12:34. The snowing continued until seven o'clock in the evening, and plowing was performed again between 15:30 and 19:00. Snowing even continued again during the night, so on Fri 2.2. the snow was plowed again between 7:00 and 16:00. Plowing was performed also on Sun 4.2. between 11:30 and 19:00. In study week three, there was only little snowfall (less than 2 cm between Fri 9.2. and Sun 11.2. The path was plowed on Sunday between 13:45 and 21:45. In study week four, on Mon 12.2. evening it was snowing, approximately 1 cm increase in snow depth. Plowing was performed on Tue 13.2. between 15:45 and 00:15. However, plus degrees and rain during the day melted most of the newly fallen snow away. Between Tue and Wed night there was also some light snowfall. The path was gritted on Fri 16.2. between 16:00 and 18:30. After Thu 15.2. temperature was constantly below zero degrees Celsius, and there were no snow events until the end of study period. No obligation for maintenance, but traffic has an impact on the packed snow and ice layer, so it could have been driven through with a harshening blade, eliminating ruts, and enhancing the friction of the surface.

On some occasions the quality requirements were not met, meaning a significant barrier for the road users. Removal of the fallen snow was usually performed almost in the given procedure time limits, meaning, that the maintenance should be performed earlier. The routes were plowed to a satisfactory level after snow events, but the freeze-thaw cycles and traffic had an impact on the road surface with packed snow and ice, which would have required plowing and roughening of the surface to provide safer and comfortable road conditions. Additionally, the underpasses and their surroundings were not maintained properly, which was said to be a result of vehicles not being able to fit in these small spaces. However, the contract obligates the contractor to have such equipment, so the requirements here were not met. During the major snow storm of Thu 1.2. conditions were exceptional, and a slight delay was understandable and acceptable. According to the regional manager, the overall maintenance was performed fairly well, taking the weather conditions into account. More significant problem is the form of reporting by the contractor. Instead of using contract-included reporting and tracking system, reporting was performed manually, written on paper by hand. This type of reporting is inaccurate, and cannot be used for more precise evaluation of maintenance performance. The system is available for the contractor, however, not used accordingly by the personnel (Salminen, 2018). Due to the inaccuracy in the reported maintenance, it cannot be said with hundred percent accuracy, whether the quality requirements were met to a satisfactory level (timings). For further evaluating the meeting of quality requirements, snow depth on road surface would have been an excellent addition to the road condition variables. It would have also been helpful to be used to evaluate the snow removal efficiency of the contractor.

The only clear phenomenon decreasing walking and cycling based on the numerical results of this study seem to be radical changes in friction, heavy precipitation and lowering temperature. Friction was somewhat constant, ~0.2-0.35, between Mon 29.1. and Sun 18.2, yet there are significant changes in traffic. Increased friction did not seem to stimulate pedestrian and cycling traffic, even though slipperiness was the strongest barrier by pedestrians, and third strongest barrier by cyclists. Precipitation was rated as the third strongest barrier by pedestrians, and fourth by cyclists. The effect of heavy snowing can be seen as sharp drops on the days it was snowing. In addition, snow on walking or cycling route was among the most important barriers, which is in line with previous studies. Answerers consider temperature to be the least and second least important factor in their moving habits, yet in larger scale the lowering of temperature also seems to lower the number of pedestrians and cyclists in traffic. Reduction in cycling traffic became apparent when temperature was colder than -10 ºC. The reduction if number of cyclists during cold weather was also noted in Helsinki (The City of Helsinki, 2016). With pedestrians, the phenomenon was not as unambiguous, yet there are some signs of walking replacing cycling, when the temperature decreases. Correspondence with previous studies is somewhat noticeable. These assumptions however, are based on manual traffic counting. To confirm the assumption, more detailed data is needed from a longer time period.

Table 5 Results about different factors impacting cycling and walking conditions

Phenomenon	Case study	Survey result (opinion)	Previous studies
Seasonal volumes	Significant reduction among cyclists (based on traffic volume counting of 2015).	Pedestrians: minor reduction in winter Cyclists: Considerable reduction in winter	Pedestrians: noticeable increase in winter Cyclists: Considerable decrease in winter
Temperature	Cold temperatures reduce the number of pedestrians and cyclists	Pedestrians: low impact Cyclists: low impact	Pedestrians: increase in T decreases activity Cyclists: increase in T increases activity However not the only factor in winter
Precipitation	Strong, reducing impact	Pedestrians: moderate barrier Cyclists: moderate barrier	Reduces the number of pedestrians and cyclists moderately. Depends also on study period.
Snow on road	Considerable barrier together with precipitation	Major barrier for both travel modes	Major barrier
Slipperiness	Strong, reducing impact, significant correlation only during change in friction.	Pedestrians: major barrier Cyclists: considerable barrier	Considerable barrier
Traffic environment		Safety of traffic environment and fluency of network are important facilitators. Separation of modes is desired.	Safety of traffic environment and fluency of network are important facilitators.

5.2 Recommendations for improving walking and cycling conditions in Turku area

One of the research questions was how to improve walking and cycling conditions. To answer this question, recommendations for improving these conditions are made. The recommendations deal with infrastructural treatments and improvements for winter maintenance based on previous studies, foreign experiments and data collection performed for this thesis.

Areas that clearly need improvement include: walking and cycling priority, pavement condition, continuity of the route, path environment and winter maintenance. According to road users, winter maintenance on study area should be improved overall. These sectors were chosen based on frequent mentions in the theory part of this thesis, observations from traffic data against weather sensor data, survey results, and observations about the study area, professional comments and documents.

According to the cycling barometer, the status of cycling and the attitudes towards developing cycling in Turku region are very positive, even among non-cyclists (The City of Turku, 2016). Campaigning for cycling is performed well, and conditions are developed for example via Civitas Eccentric salt brushing test route. However, few cyclists felt that some additional campaigning would be useful. Especially attitude education for car drivers would increase traffic safety among cyclists.

5.2.1 Improvements for the traffic environment

This section presents answers for the research question "How can walking and cycling environment be improved for pedestrians and cyclists? " The answers include recommendations and suggestions for improving the walking and cycling environment through infrastructural treatments. Some of the recommendations and suggestions are appointed to the study area in particular, but some are applicable in other locations as well. In general, the treatments should deal with improving safety, feeling of it, and continuity of routes. To promote active travel modes, urban environment should be designed for people, not cars (Pucher & Dijkstra, 2000).

The most important and urgent improvements for the traffic environment:

- **Repairing the pavement where required**
  There is some unevenness, cracks and other damages on the route, which leads to incomplete snow clearance and water puddles. Repairing the pavement will improve the usability and walking and cycling experience of the route. Smooth, adequate road surface will also enable a better result in snow removal. Repairing the pavement (where required) is also important on other routes.

Measures to improve the traffic environment and safety:

- **Changing and/or complementing certain segments on the route, improving the continuity of the route.** In smaller, detailed cases, for example sharp edge curb stones cause discomfort to some and may even break tires or wheels.

- **Separation of traffic modes**
  Separating walking and cycling from each other and motor vehicles increases the traffic safety of all groups, and was frequently mentioned by both pedestrians and cyclists as a way to improve conditions. Currently part of the route is also shared with motor vehicles. Some already prepared plans aim to fix some of these.

- **Walking and cycling specific facilities increasing safety and comfort**
  Current plans already include some leaning rails with crossing light controlling buttons for cyclists. Next steps could be for example bicyclist and pedestrian detecting traffic lights, so that the cyclists would not have to stop to wait for the light to change to green. For longer time period, active travel mode promotion should include more extensive measures, such as traffic calming and restrictions for motor vehicles.

Methods to increase the maintainability. To be considered in planning of new routes, and repairing of existing routes:

- **Planning of underpasses and intersections with maintenance in consideration**
  Fitting of vehicles in the underpass should be considered in the planning phase, even though smaller maintenance vehicles are available. However, the efficiency of maintenance would improve if the maintenance of the entire route could be performed with a single vehicle. In addition, the large ice fields, which formed around underpasses this winter, can be reduced by correct drainage.

- **Accommodation of snow**
  In locations where the pedestrian and cycling path run directly next to the roadway, snow is plowed onto these combined paths. In design phase of constructing new paths and repairing currently existing ones, this should be considered with providing a zone for storing snow. The problem could also be solved by timing the plowing of the pedestrian and cycling path immediately after the roadway. Special attention should be paid on accommodation of plowed snow on bridges.

5.2.2 Improvements for winter maintenance processes

To answer the final research question ("What kind of winter maintenance practices should be continued and developed in the study area? "), recommendations and suggestions for improving and developing the winter maintenance were made. Similar to suggestions for improving walking and cycling improvement, some of the recommendations are specialized for the study area, some are applicable to locations with similar climate, and some suggestions are usable regardless of the location or the type of climate.

Recommendations for improvements to winter maintenance particularly in the study area (i.e. highest priority):

- **Ensuring the fulfillment of contracts, improved communication between different organizations and stricter enforcement**
  The current instructions for making a contract, and operations and enforcement during contract period are extensive, even though they are somewhat complex. More frequent communication with the contractor to determine agreements about the road condition to improve quality. For example, physically going through the path to show desired results. Quality could also possibly be improved through stricter enforcement. Reporting according to contracts would also help the ordering organization to focus the attention where needed, and in this case also provide the contractor with valuable data for optimizing their operations .

- **Changeable snow removal tools for different road surface conditions**
  When used before the freezing of (partly) melted snow, for example snow brushes clear the road surface better than a plow. For larger amounts of snow plows are the best option. On frozen surfaces, ruts should be removed, and the remaining surface roughened with indented blade. Extremely generalized, plows are better for locations where the winters are colder, without freeze-thaw cycles, and salt brushing is better in locations where temperature does not go or stay under zero degrees for a longer period.

- **Coordinated friction and pollution control of road surface**
  Currently only gritting is used on the study route. Salt could be used to keep the road surface clear of snow and ice. However, salt should be used as a solution to minimize the negative impacts. Mixing the solution with additives will improve the ice melting qualities and adherence to road. Additives such as molasses and other by-products would also reduce the loss of these products for the manufacturers. Use of salt brine would also eliminate the need for sand collection in springtime and improve air quality during the collection. Properly designed and repaired road would also be puddle free. Environmental impacts of salt could be minimized by constructing subsurface drains under shoulders. Grit of smaller grain size, warm wetted sand, Swiss salty wood chips could also be a suitable solution.

- **Proactive maintenance before snowfall for salt use minimization**
  If salt (brine) is taken into use, it could also be used for proactive maintenance by spreading brine onto roads before snowfall, which will make the snow removal after the snow event easier, and also decrease the total amount of salt needed.

- **Storage and depot locations, and utilization and updating of stock**
  Currently the LM-Trac of the contractor could be used for plowing and gritting. However, it is not used for gritting, since it cannot carry enough material to last for the whole study route. Having an additional grit storage nearer the maintenance area could be used to load grit on the combined plow and gritting vehicle, so the route could be maintained with a single vehicle instead of two vehicles performing the plowing and gritting separately. Evaluation of cost-effectiveness in general could help find sector, where savings could be made, and this money could be used for improved maintenance. Investments considering stock should be targeted at vehicles capable of clearing underpasses as well, but also to enable spread brine. Investing in modular equipment will minimize the number of base vehicles needed.

- **Utilization of existing, and development of maintenance management support systems**
  Making the most out of the software already in use can be used to improve efficiency and reporting. Developing the system and linking weather and road condition data to it to enable real-time automatic routing and maintenance methods based on priorities and current road conditions will improve the overall efficiency of the contractor and traffic network. For example, advising to spread salt brine on routes prior to snowfall, if the snow is expected to melt anyway after the snow event, otherwise wait for the snowing to end and clear the snow afterwards.

Recommendations for improving the maintenance of walking and cycling paths in a longer time interval (i.e. policies, strategic development and promoting plans):

- **Increasing the priority of maintenance of pedestrian and cycling paths**
  Cars, trucks and buses can operate on light snow more easily than pedestrians and cyclists as they have more mass and contact points with the road than pedestrians and cyclists. Priority of the maintenance routes in the transport system should be reevaluated in accordance with the modal priority in strategic transport system documents on different administrative levels.

- **Adaptivity for the quality requirements**
  Currently, the requirements are defined almost solely with numerical definitions (for example snow depth) or loosely (for example "in adequate condition"). In some situations, for example the amount of snow might fulfill the quality requirements, but might not be comfortable to use. Loose definitions should be modified so that there is no chance of misunderstandings, for example with benchmarks. The quality requirements (for roads under the administration of the Finnish Transport Agency) are also defined similarly for the entire country, not taking local factors, such climate into account. By allowing different maintenance methods more suitable for local conditions, quality and service level could be improved significantly.

- **Increasing winter maintenance budget**
  Obviously, if contractors have more money to use, they can increase the size of personnel and stock and spend more time on maintenance and management. As previous studies say, investment in winter maintenance most probably will pay itself back in several forms of savings, such as reduced injury treatment costs, health benefit savings etc.

- **Simplifying administrative procedures**
  Currently the chain goes through Finnish Transport Agency being responsible for the road and defining methods and quality requirements, Centre for Economic Development, Transport and the Environment being responsible for the operative aspect and monitoring for example the maintenance, contractor responsible for performing maintenance and subcontractor doing the actual maintenance. Additionally, prioritizing and developing of roads belonging to the state might become a complex process for local governances, aiming to improve the mobility on a local scale. Dividing parts of the road to be administrated y other organizations could simplify these issues considerably.

- **Development of contract models**
  Currently the roads under the administration of Finnish transport agency are maintained under an areal contract. Dividing some of the roads under a route-specific contract could help optimizing maintenance costs and improve the quality of the route, when the contractor maintaining the route may focus and specialize the resources more accurately.

- **Implementation of road weather data collection systems**
  Expanding the weather data collection on pedestrian and cycling paths will help keeping track of maintenance areas. Static measuring points are relatively easy to set up, but realization of dynamic walking and cycling network weather data collection is challenging, as the weather sensors need electricity. Developing battery-based sensors could solve the

problem. Other ways to evaluate route condition could be travel time -based estimations using GPS-tracking.

5.2.3 Promotion of walking and cycling

Cycling in Turku region is seen as a positive mode of transport, and a clear majority of the residents support the development of cycling. Cycling is actively promoted, and conditions developed by the cycling association. Campaigning could improve the position and evaluation of cycling even further. Programs combining improvements of infrastructure and winter maintenance together with attitude education could increase cycling levels in the region.

Some of the safety increasing measures mentioned both groups were reflectors for road users and attitude education for car drivers. Even though cycling has a positive image in Turku, some feel that the negative attitudes of car drivers towards cyclists cause feeling of unsafety. Cyclists should be considered as slow vehicles instead of pedestrians on wheels (Maijala, 2011). Previous studies suggest, that traffic education should be arranged for cyclists (and pedestrians) as well. Additional campaigns promoting cycling and walking could be arranged to increase the share of these travel modes. These could include for example kilometer competitions and cycling encouraging programs at workplaces. On a political level, for example tax reliefs have a great potential in increasing cycling.

The survey results revealed, that pedestrians and cyclists would like to be informed better about the route condition and maintenance. Currently, such information is available mostly on major roadways. Maintenance history of walking and cycling paths is available for public only on few cities, on certain routes. In addition, maintenance feedback is given through various channels. The information is fragmented into several different services, of which only a part of is open to the public. A more open and easily reached information would increase the influence of individual road users, pointing out issues that need improvement, which also might not otherwise be noticed.

A single system, for example a map based web page, which would show road condition, maintenance history, supervisor, unit responsible for organizing maintenance, contractor, subcontractor and real-time location of the maintenance vehicles would provide road users the information they want. This kind of system could also be used for reporting (by the road users) locations that need repairing, maintenance or other measures. Such systems already exist as separate services, so the workload of developing such system consists mainly of combining the data from several separate sources and interfaces. Extensive use of this system would also require that all maintenance vehicles are equipped with technology compatible with the data system. However, the survey answerers evaluated the real-time information about winter maintenance to be the more important than about road condition. The development of such extensive system just described should be started with providing open information about the winter maintenance of walking and cycling paths, with possibly showing maintenance vehicles on map. According to the survey results, this would increase the amount of walking and cycling during winter. The service should also include commenting possibility for easy reporting of problematic locations, notifying the maintenance supervisors and contractors.

6 Conclusions

This thesis studied the impacts of traffic environment, weather, road conditions and maintenance on walking and cycling conditions, with a focus on improving these conditions especially during winter time. These topics were studied in literature review and a case study, locating on the walking and cycling paths of the road 110 between Turku and Kaarina. In the case study, data was collected with road weather sensors, traffic counters and a user survey.

The first objective of the study was to determine the weather and road conditions in the study area. During the data collection period between 22.1. and 4.3.2018 the weather and road conditions varied considerably. During this period, the road surface temperature ranged from slightly above zero down to -16 degrees Celsius, while road conditions varied from clear to snowy and icy. Besides road surface temperature, dew point, relative humidity, friction water layer width and ice percentage were monitored, and these numerical values could be linked to specific outdoor conditions. During the same study period, also traffic volumes of pedestrians and cyclists were counted using traffic counting devices. Due to these devices being designed primarily for counting motor vehicles, manual counting was performed weekly to evaluate their accuracy with pedestrians and cyclists, and adjusted when required. The results were then linked to data produced by the road weather sensor. To compliment these results, a user survey was performed to receive empirical data about the same phenomena.

Another part of the study was to evaluate the impact of different factors on walking and cycling. In this study, based on the sensors, the most apparent variables having a significant impact on walking and cycling traffic volumes are precipitation and outdoor temperature. Considerable drops in road user volumes occurred during days with snowfall (Wednesday 24.1. and Thursday 1.2.). In longer time span inspection, besides precipitation, the only other variable traffic volumes seemed to correlate was temperature. As the outdoor temperature decreased, so did the road user volumes. With the majority of the path users consisting of cyclists, it can be said, that the previous study results point in similar direction. Instead, according to the survey results, the impact of temperature could be expected to be less significant. On the other hand, during the colder period, there was practically no maintenance due to lack of snow days, so the surface of the snow and ice-packed road was slowly molded by the road users. Precipitation seemed to have a more significant impact on pedestrians and cyclists than previous studies and survey results would suggest. However, the form of precipitation was snow, meaning it piled on the road surface and became a much greater barrier, which would be in line with the survey answers and previous studies. In the case of previously described scenarios, the importance of winter maintenance for pedestrians and cyclists cannot be belittled.

It is established, that winter maintenance is a major facilitator of walking and cycling, and should thereby be emphasized to promote these travel modes. Third focus in this study was to determine the problems and targets of development in winter maintenance. Often the resources are directed to other modes, and walking and cycling are prioritized lower. Significant improvements in walking and cycling conditions could be achieved by performing the maintenance according to contracts and agreements already defined, but also developing maintenance and methods. To begin with, maintenance should be planned with local conditions considered, specializing methods suitable for use and resulting in the best outcome. In the case of Turku (and other cities with similar climate), investing in equipment for clearing light sets of snow and slush should be considered. A practical solution already used abroad is salt brushing. If possible, the opinions of local people about the efficiency of the method on test routes should be considered. Should such method be implemented, it is suggested that salt is spread as a solution to minimize its negative impacts. Additives are also recommended to be used to improve the qualities of salt brine and utilization of by- and overproduction.

To improve the efficiency and cost-effectiveness of maintenance, informational systems should be considered. With automatic performance tracking systems, for example the resources could be directed accordingly, but also other sectors examined and improved. These systems can also be used for improved communication, and easier, more detailed and efficient reporting, which could then be used for quality monitoring. Information about real time winter maintenance could also be exported available for the public. Such services already exist, but mainly for motorists. According to the user survey results, information about the maintenance of the route would be highly appreciated, and would also increase walking and cycling activity.

The final aim of this study was to find ways to improve the walking and cycling environment. For the maintenance to be successful, also the physical environment should be suitable for maintenance. It is important to ensure that the environment is in appropriate condition for the maintenance equipment to be used accordingly. Good condition of the traffic environment also increases the usability and safety of the route. Other physical, user comfort increasing measures can be implemented through design and construction of continuous and safe transportation infrastructure. Facilities designed for people instead of cars has been noticed to increase the modal shares of walking and cycling. A good example of these is separating different travel modes to their own spaces, such as cycle tracks. Traffic environment should also be considered on an unphysical level. Attitudes of different road users are a principal factor in creating a safe transportation system. Various programs and campaigns could be organized to promote the active travel modes, especially in areas where these modes are less popular. For these attempts to success, walking and cycling need to be made easy and attractive.

Further study resources related to this topic are suggested to be directed to evaluate the efficiency of promotional campaigns and programs to determine the appropriate allocation of resources in walking and cycling promotion. Cost-benefit and development possibility analyses on informational systems of (walking and cycling) infrastructure winter maintenance for public road users combining different functions under a single service are recommended.

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Appendixes

Appendix 1. Survey questions

Are you answering the survey for the first time?

- Yes
- Second time answering, but this time from a different perspective (cyclist/pedestrian) than the first time

Are you answering this survey as a cyclist or a pedestrian?

- Cyclist
- Pedestrian

1. How often do you cycle during the summer season? / How often do you make walking trips during the summer season?

- Five days a week or more often
- On 2-4 days a week
- One day a week
- Several times in a month
- Several times in the season
- Less

2. How long (in average) is your cycling/walking trip in the summer season?

3. Main purpose of your cycling/walking trip (in the summer season)?

- Work or school
- Business
- Shopping
- Errands
- Leisure activity
- Sport
- Other, please specify

4. How often do you cycle during the winter season? / How often do you make walking trips during the winter season?

- Five days a week or more often
- On 2-4 days a week
- One day a week
- Several times in a month
- Several times in the season
- Less

5. How long (in average) is your cycling/walking trip in the winter season?

6. Main purpose of your cycling/walking trip (in the winter season)?

- Work or school
- Business
- Shopping
- Errands

- Leisure activity
- For sport purpose
- Other, please specify

7. How strong of an impact do you experience following characteristics having on your cycling/walking in winter?
1 = no effect, 5 = prevents me from cycling/walking.
- Temperature
- Wind
- Precipitation
- Darkness
- Slipperiness
- Snow on cycling/walking path
- Snow blocking visibility
- Rutted cycling path (only for cyclists)
- Other, please specify

8. How do you evaluate following characteristics of the cycling/walking path between Turku and Kaarina?
1=very poor, 5 very good, Don't know
- The condition of the pavement
- Lighting
- Cycling facilities / taking pedestrians into account
- Safety
- Overall review of the cycling path (only for cyclists)

9. How do you evaluate following parts of winter maintenance on the cycling/walking paths between Turku and Kaarina?
1=very poor, 5= very good
- Result of snow removal
- Timing of snow removal
- Accommodation of snow
- Skid control methods
- Skid control results
- Skid control timing

10. How would you develop winter cycling/walking conditions?
Checkbox answers:
- Different snow removal methods (for example snow blower, brush)
- Use of salt and/or other skid control methods
- Other, please specify

11. If the things you mentioned earlier were fixed, how often do you believe you would cycle / how often would you make walking trips during the winter season?
- Five days a week or more often
- On 2-4 days a week
- One day a week

- Several times in a month
- Several times in the season
- Less

12. What things and/or measures would get you to use the cycling/walking paths more often (especially during winter)?

13. Would you consider for example an app or map service, where you could check following things, to be useful?

- Condition of the road (temperature, humidity, ice status, friction)
- Timing of winter maintenance actions

14. What kind of effect do you believe such system would have on your cycling/walking?

- I would cycle/walk more
- No effect
- I would cycle/walk less

15. I am a member of Turku cycling association TurPo ry (Turun polkupyöräilijät ry)

16. As a member of TurPo ry, I feel I can influence following things
1=not at all, 5=significantly.

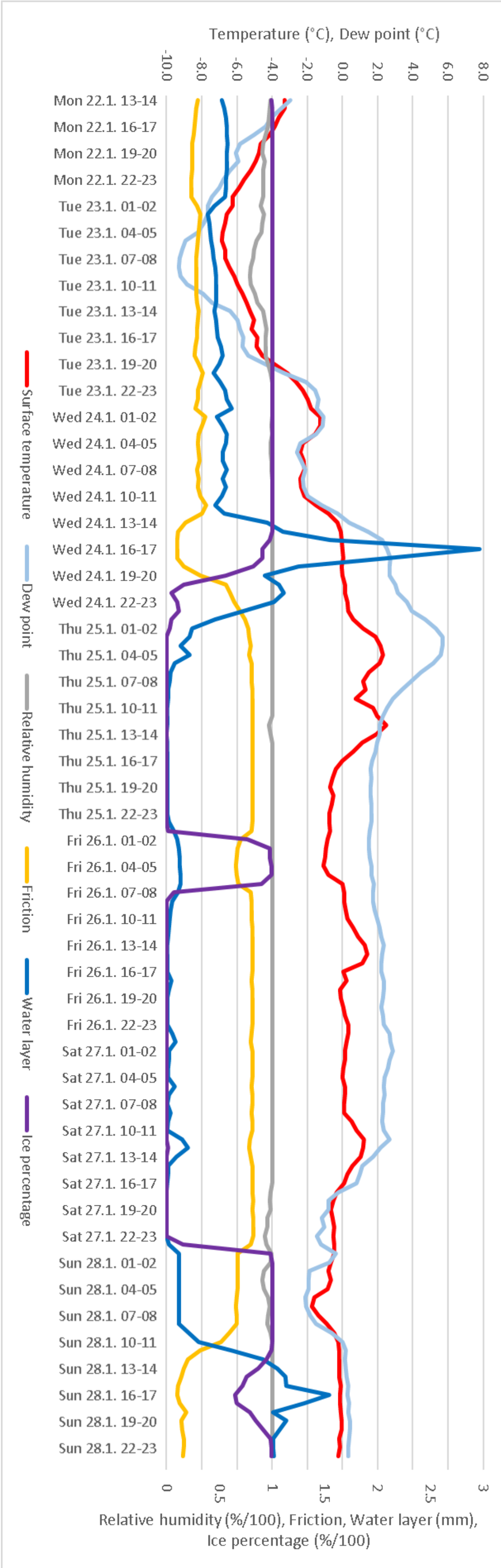
- Design of the cycling paths
- The condition of cycling paths
- Winter maintenance
- Promotion of (winter) cycling
- Other, please specify
- Other, please specify

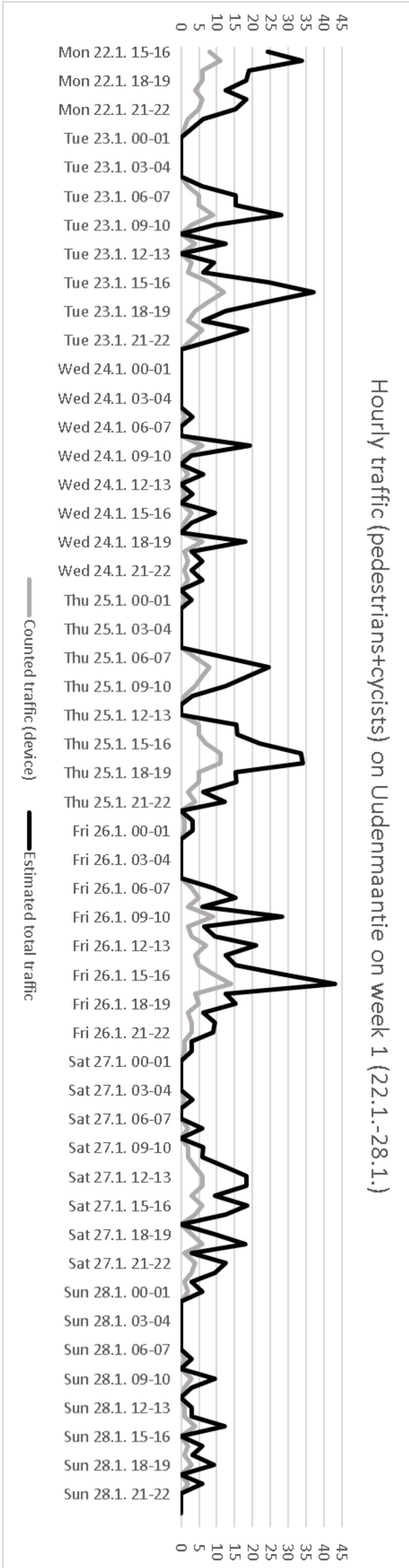
How did you find out about this survey?

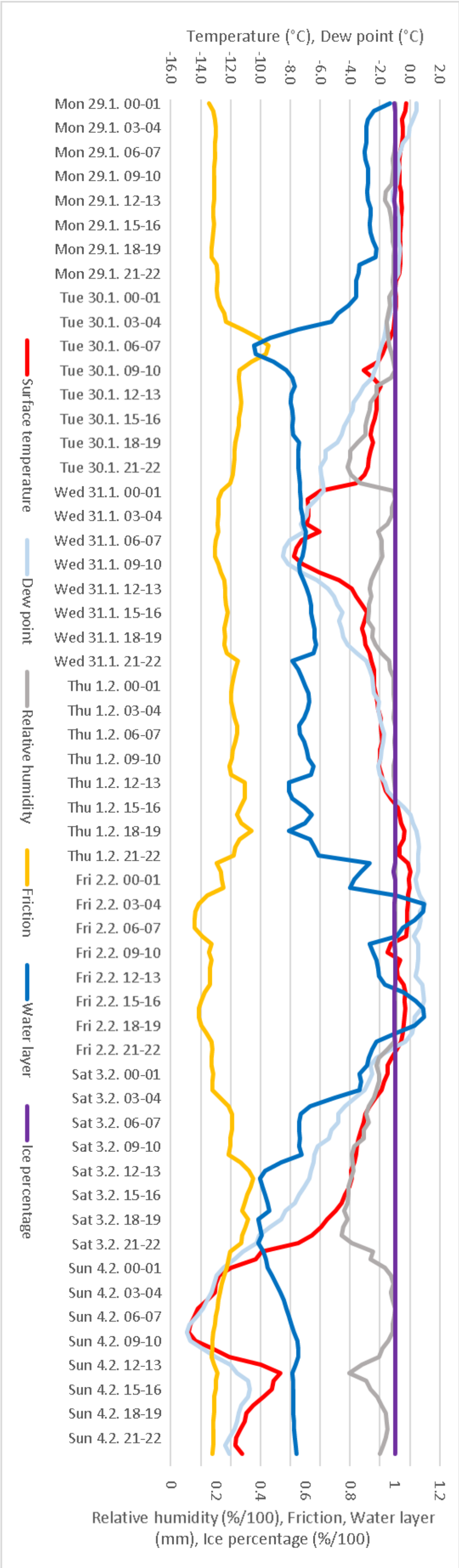
- Newspaper announcement
- Social media
- Heard from an acquaintance
- I was given a flier
- Other, please specify

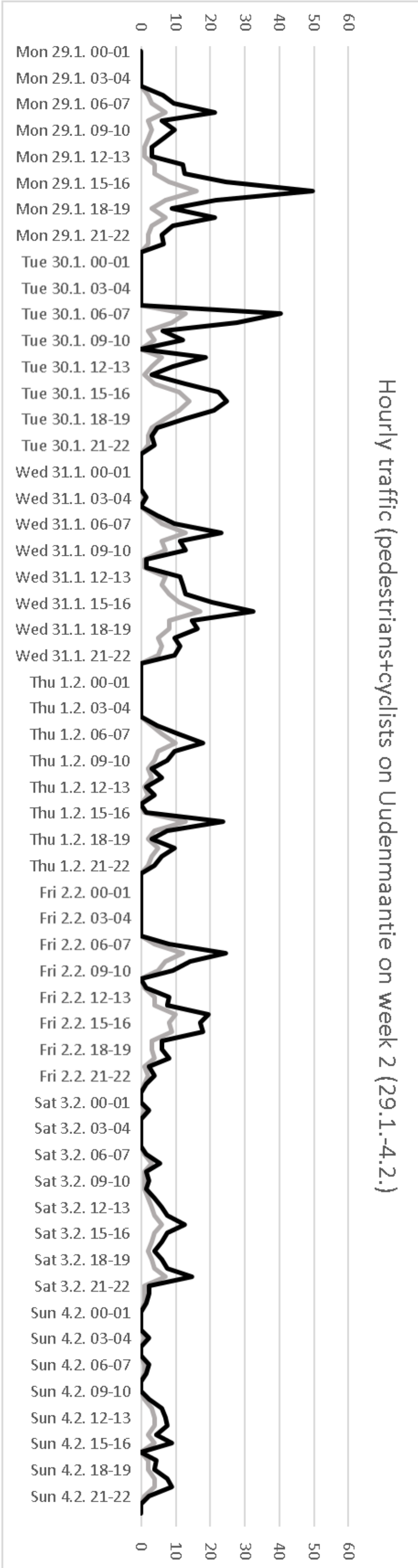
Open comments

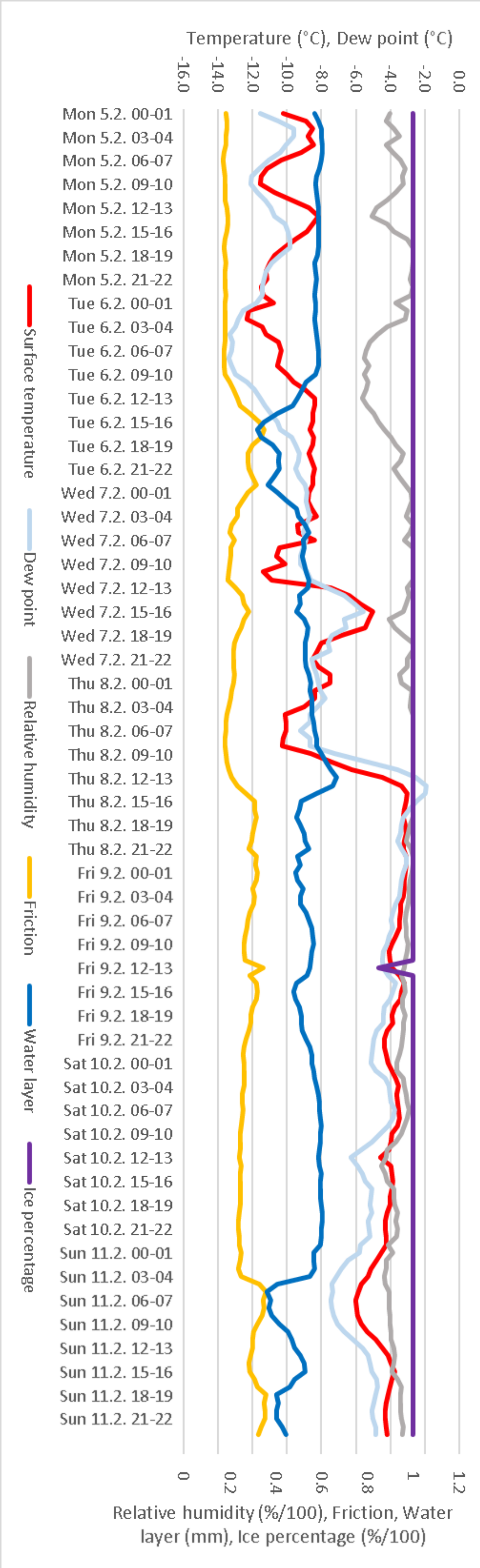
Appendix 2: STARWIS and traffic data weekly

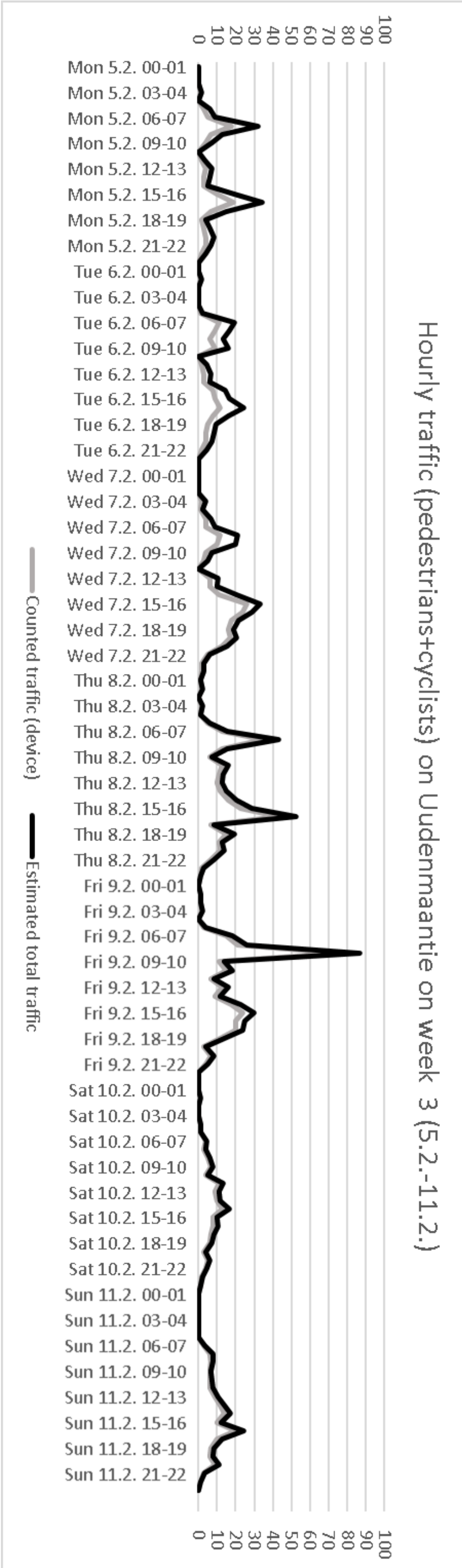


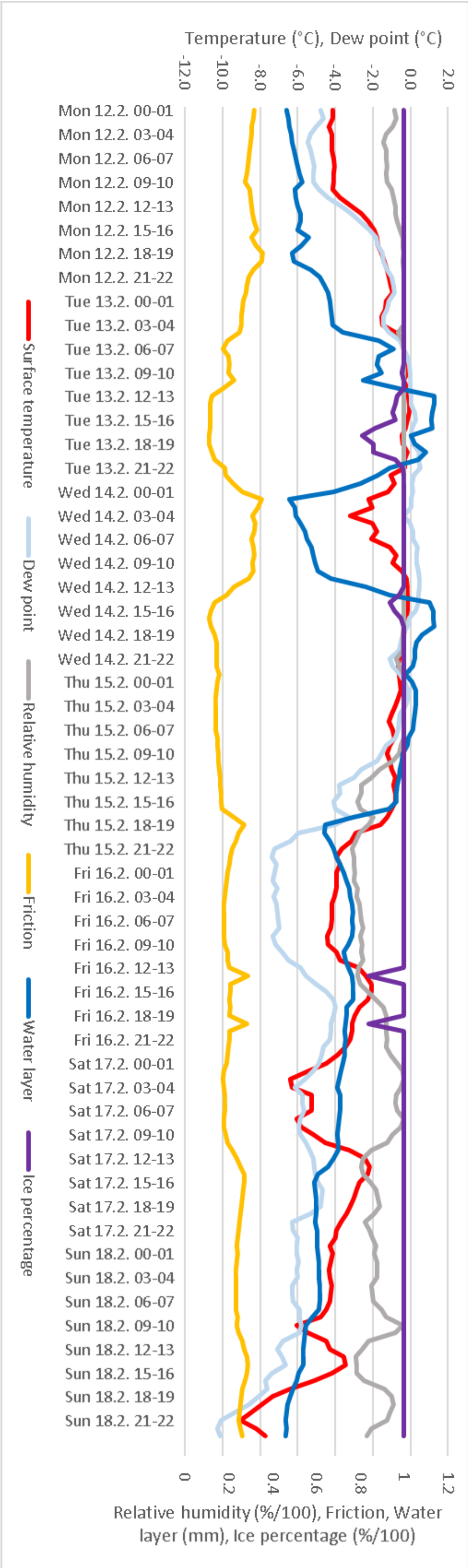


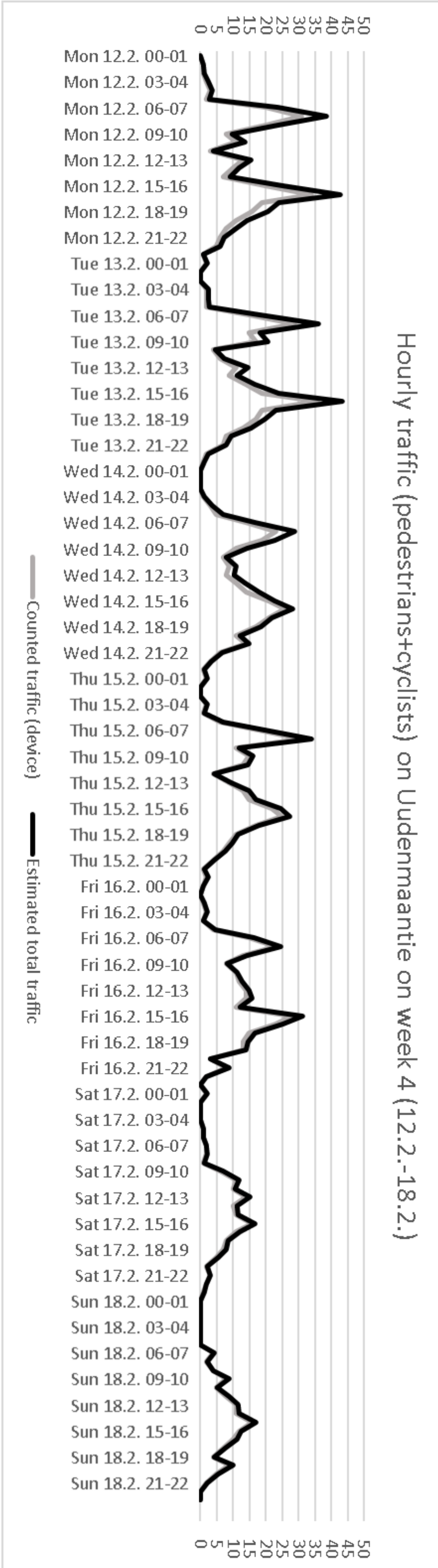

Temperature (°C), Dew point (°C)
Relative humidity (%/100), Friction, Water layer (mm), Ice percentage (%/100)
Surface temperature
Dew point
Relative humidity
Friction
Water layer
Ice percentage

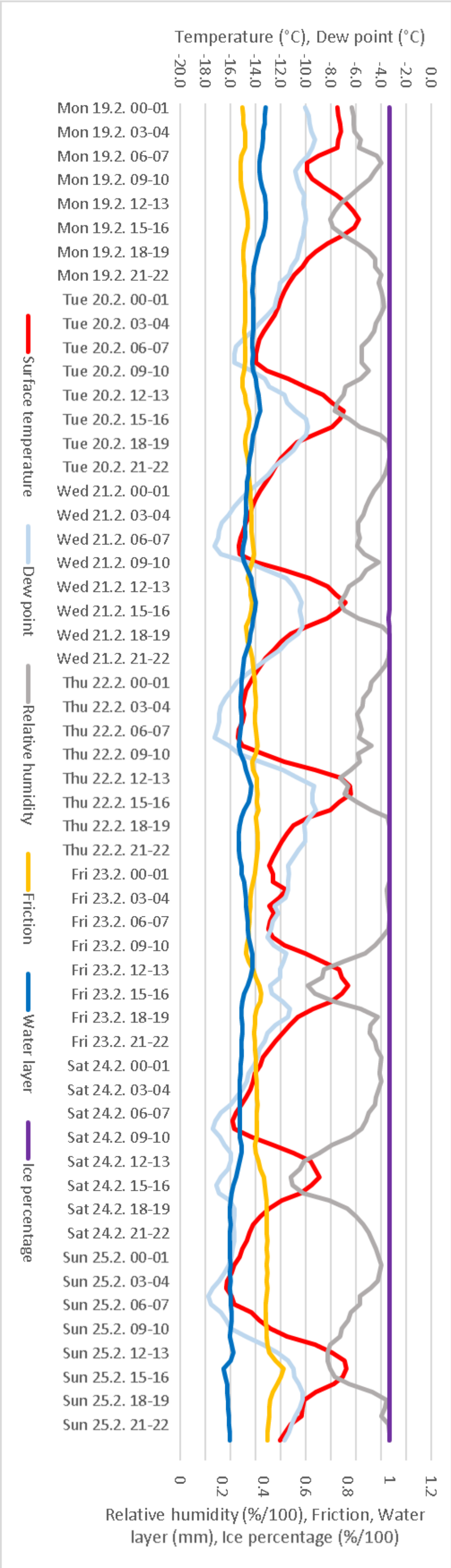

Hourly traffic (pedestrians+cyclists on Uudenmaantie on week 2 (29.1.-4.2.)

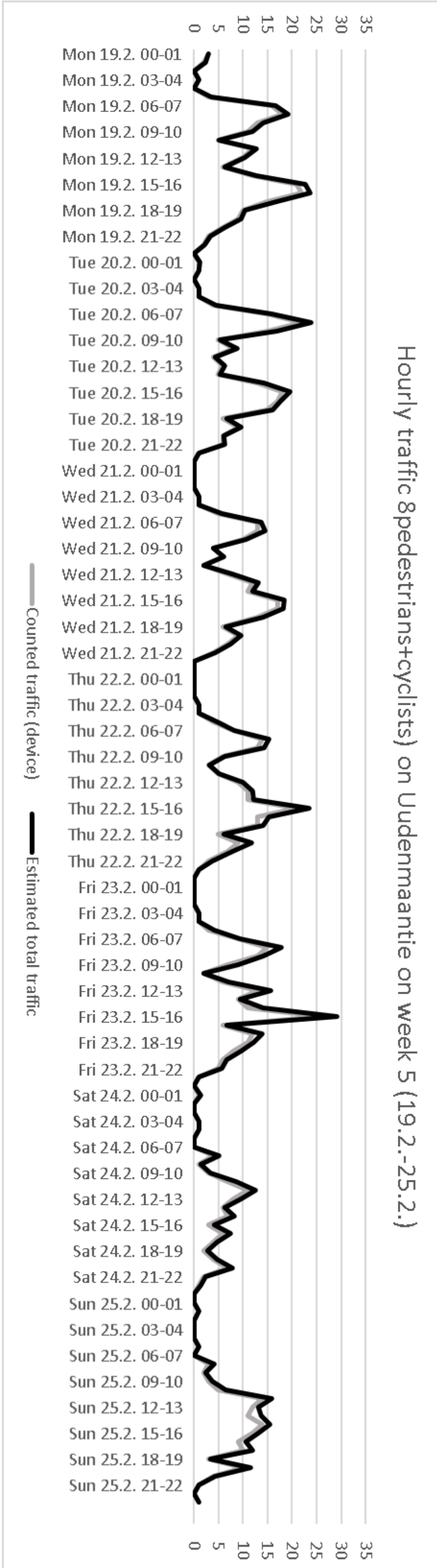

Temperature (°C), Dew point (°C)
Relative humidity (%/100), Friction, Water layer (mm), Ice percentage (%/100)
Surface temperature
Dew point
Relative humidity
Friction
Water layer
Ice percentage

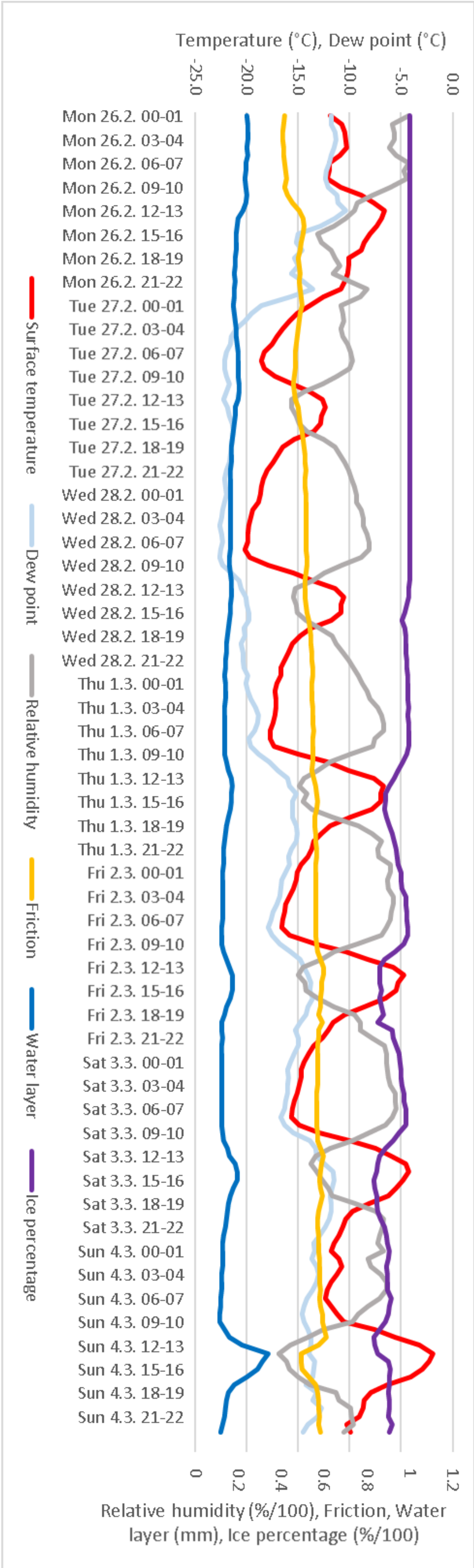

Hourly traffic (pedestrians+cyclists) on Udenmaantie on week 3 (5.2.-11.2.)
Counted traffic (device)
Estimated total traffic

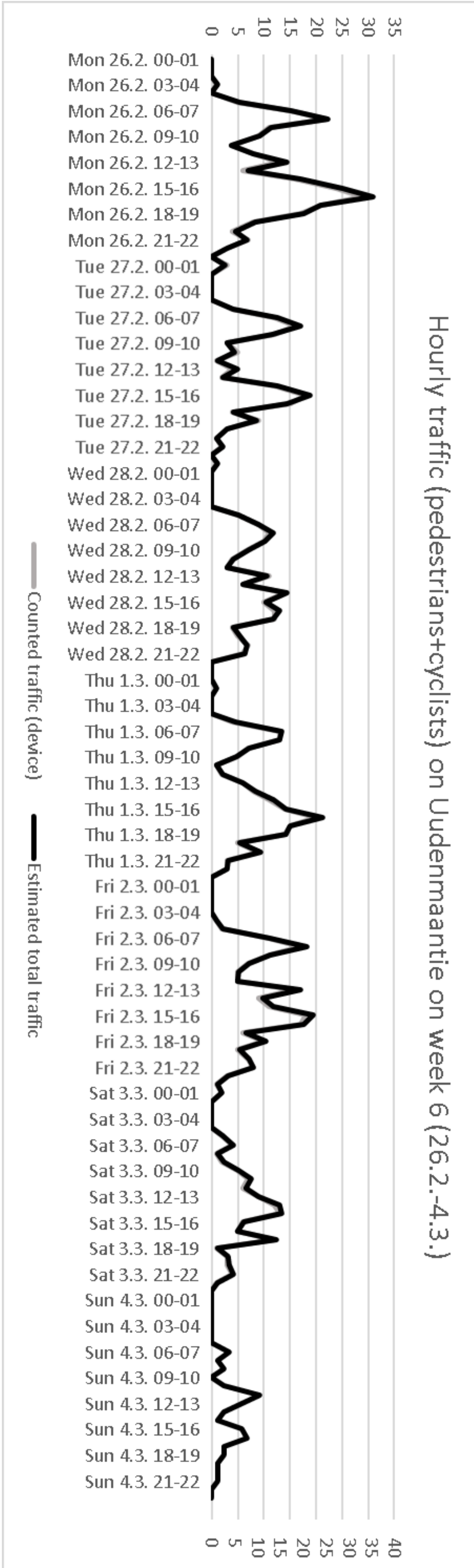

Temperature (°C), Dew point (°C)
Relative humidity (%/100), Friction, Water layer (mm), Ice percentage (%/100)
Surface temperature
Dew point
Relative humidity
Friction
Water layer
Ice percentage


Hourly traffic (pedestrians+cyclists) on Uudenmaantie on week 4 (12.2.-18.2.)
Counted traffic (device)
Estimated total traffic


Temperature (°C), Dew point (°C)
Relative humidity (%/100), Friction, Water layer (mm), Ice percentage (%/100)
Surface temperature
Dew point
Relative humidity
Friction
Water layer
Ice percentage


Hourly traffic 8pedestrians+cyclists) on Udenmaantie on week 5 (19.2.-25.2.)
Counted traffic (device)
Estimated total traffic


Temperature (°C), Dew point (°C)
Relative humidity (%/100), Friction, Water layer (mm), Ice percentage (%/100)
Surface temperature
Dew point
Relative humidity
Friction
Water layer
Ice percentage


Hourly traffic (pedestrians+cyclists) on Uudenmaantie on week 6 (26.2.-4.3.)
Counted traffic (device)
Estimated total traffic